Structural-stratigraphic evolution of Italy and its petroleum systems

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ABSTRACT

The geological evolution of Italy was controlled by Triassic-Early Jurassic rifting, culminating in the separation of the European, African and Adriatic plates, by their interaction during the Mid-Jurassic-Early Cretaceous opening of Tethys and the Mid-Cretaceous and Cenozoic closure of Tethys. During the break-up stage, a complex system of carbonate platforms and intervening troughs developed on the Adria plate. These contain laterally discontinuous Middle Triassic to Early Jurassic oil source-rocks. Cretaceous to Eocene subduction of oceanic basins and Oligocene to Recent continental collision governed the development of the Alpine and Apennine orogens. In foredeep basins associated with these evolving fold- and thrustbelts, thick Neogene flysch successions were deposited. These contain some oil source-rocks as well as sizable amounts of biogenic gas.

Italy's URR amount to $131 \cdot 10^6$ t of oil and condensate and $743 \cdot 10^9$ m^3 gas. The oil and gas fields discovered in Italy can be grouped, according to charge-providing source-rocks and processes controlling their maturity and trap development, into several petroleum systems. Definition of some of these systems remains, however, tentative due to insufficient data.

The main oil fields, accounting for 13% of Italy's URR, were charged by Triassic-Jurassic source-rocks. These attained maturity during the Late Neogene in rapidly subsiding foreland basins. Hydrocarbons generated charged by prevailingly vertical migration block-faulted foreland structures and anticlinal features of the external thrustbelts. The charge factor of Triassic source-rocks is low. The retention capacity of seals is generally limited.

Miocene flysch is the source of thermal gas and light oil in the Apennine thrustbelt. Moreover, Miocene flysch series contain minor and marginal accumulations of bacterial gas in the eastern parts of the southern Alps, the southern Adriatic Sea and in western Sicily. The bulk of Italy's hydrocarbon reserves consists of bacterial gas contained in Pliocene and Pleistocene flysch. Although bacterial gas accumulations occur in many basins and in different traps, optimal conditions prevail in the northern Apennine foredeep which is characterized by high sedimentation rates, multiple reservoir/seal pairs provided by highly efficient turbidites and synsedimentary trap forming conditions.

List of abbreviations: HI=hydrogen index, HC=hydrocarbons, SPI=source potential index,

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This article includes 3 enclosures on 1 folded sheet.

TOC=total organic carbon, URR=ultimate recoverable reserves

INTRODUCTION

Italy's on- and off-shore basins and external fold- and thrustbelts host a large number of hydrocarbon plays. Many of the already discovered hydrocarbon accumulations can be related to specific source-rocks. The interdependence of factors and processes controlling the formation of hydrocarbon accumulations has been discussed in previous reviews of Italy's petroleum geology (Pieri and Mattavelli, 1986; Riva et al., 1986; Mattavelli and Novelli, 1988, 1990; Mattavelli et al., 1993; Zappaterra, 1990, 1994)

Since 1944, about 2500 exploration wells were drilled in Italy's on- and off-shore plays. These resulted in the discovery of numerous oil and gas fields (Fig. 1) having cumulative URR amounting to $131 \cdot 10^6$ t (950×10^6 bbl) of oil and condensate and $743 \cdot 10^9$ m^3 (27.6 TCF) gas (cut off date 31.12.1994). Italian fields produced in 1994 a total of $4.9 \cdot 10^6$ t of oil and $20.6 \cdot 10^9$ m^3 gas. This approximately corresponds to 14.1% of Italy's energy requirements.

This paper is mainly, but not exclusively, based on the data and conclusions previously published by the authors and their colleagues of Agip S.p.A. The stratigraphic and structural evolution of Italy is reviewed in a geodynamic framework with special emphasis on the source-rock habitat. A preliminary classification of Italy's petroleum systems, referring to examples of commercial accumulations, is presented. However, in some cases, the paucity of information on source-rocks does not permit an adequate definition of the respective charge system.

GEODYNAMIC EVOLUTION OF ITALY

The Mesozoic and Cenozoic stratigraphic and structural record of the Italian sedimentary basins and fold- and thrustbelts has greatly contributed to the understanding of the geodynamic evolution of the Central Mediterranean area, main stages of which were the Triassic-Jurassic break-up of Late Palaeozoic Pangea, resulting in the opening of the Tethys system of oceanic basins, the separation of the Eurasian, African and Adriatic (also referred to as Apulia or Italo-Dinarid) plates, and the development of passive margins, followed by the Cretaceous-Cenozoic convergence and collision of Africa and Europe, causing the deformation of the intervening Adria plate and the development of the Alpine and Apennine orogens (Biju-Duval et al., 1976; Laubscher and Bernoulli, 1977; Tapponier, 1977; Bernoulli et al., 1979a, 1979b; Dercourt et al., 1985, 1986; Ziegler, 1988, 1990; Dewey et al., 1989; Boccaletti et al., 1990).

In the following we retrace the Triassic to Neogene evolution of Italy in a plate-tectonic framework. The following four stages can be distinguished (Fig. 2):

Permo-Triassic Rifting Stage (Fig. 3a)

At the end of the Hercynian (Variscan) orogeny, during which the Pangea super-continent was consolidated, a tensional tectonic regime prevailed in the Central Mediterranean area. Initially continental clastics were deposited in incipient rifted basins. As these were gradually invaded by the transgressing Tethys Sea, evaporitic series were deposited. This was followed by the establishment of a complex system of carbonate platforms and intervening deeper water troughs. By Late Triassic times, the Apulia Platform was flanked to the East by the Olenus-Pindos and Sub-Pelagonian and to the West by the Lagonegro deeper water troughs, and to the North by the South-Alpine, Austroalpine and Piedmont rift systems.

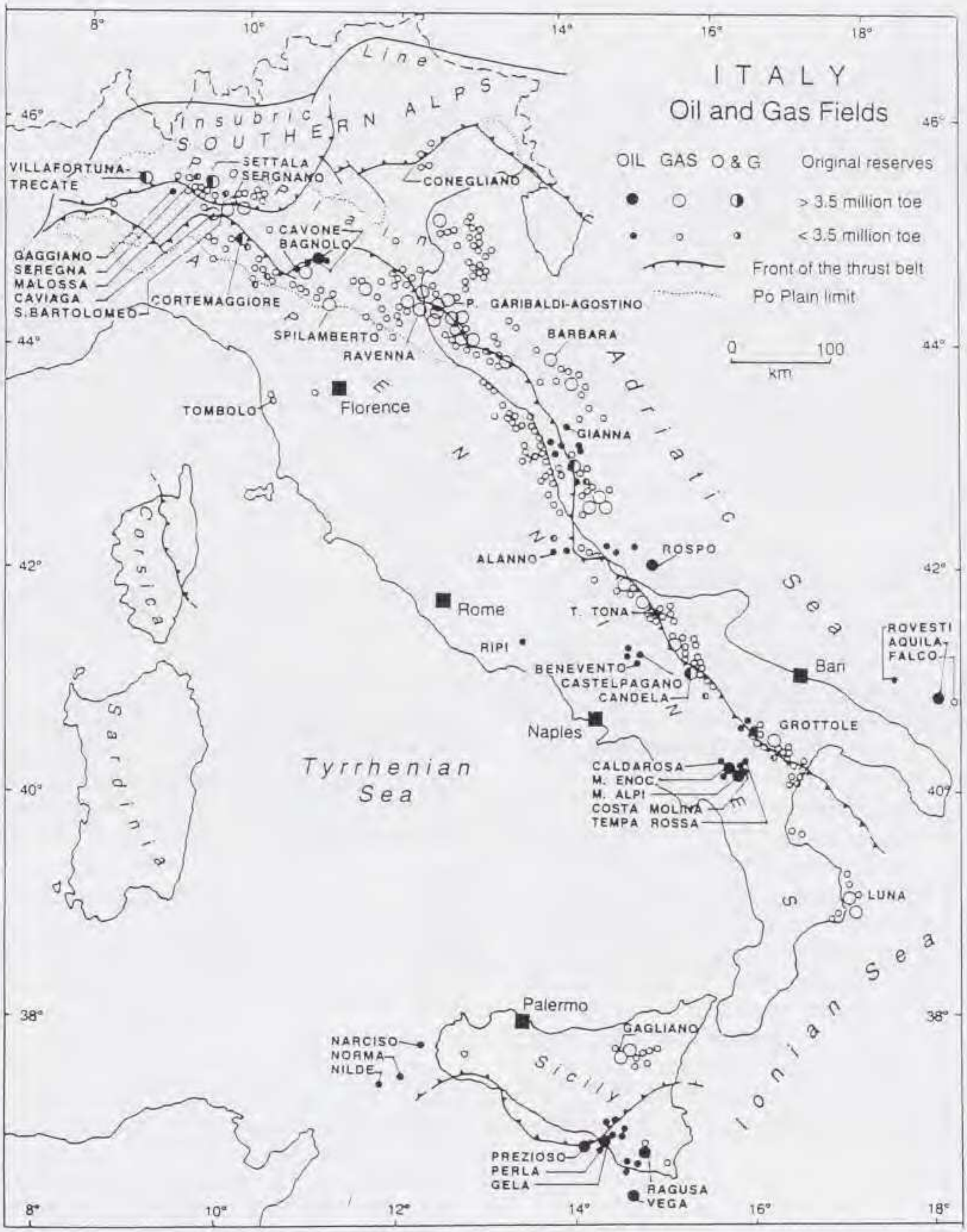


FIG. 1. Italy: oil and gas fields. Fields mentioned in the text are named.

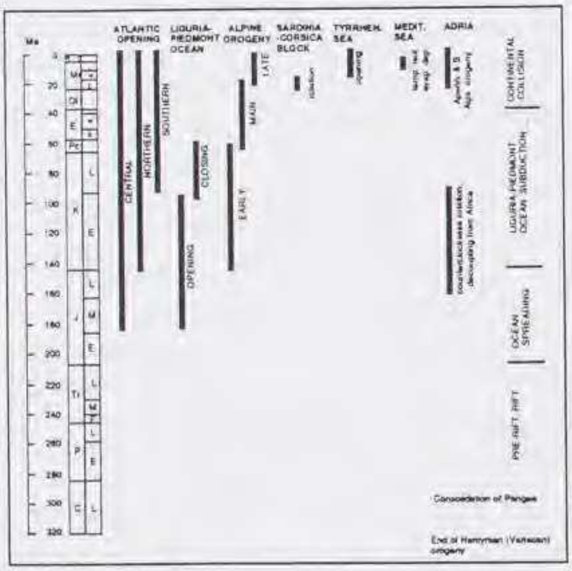


FIG. 2. Chronologic chart of the main geodynamic events in the Mediterranean and Atlantic areas.

Jurassic Sea-Floor Spreading Stage

Rifting activity continued during the Early Jurassic and culminated in early Mid-Jurassic crustal separation between the Adriatic and European plates and the transtensional opening of the Alboran-Ligurian-Piedmont-Penninic ocean. During the Late Jurassic, the oceanic Vardar Basin began to close in response to sinistral translation of Africa relative to Europe, induced by the progressive opening of the Central Atlantic. At the same time, the relatively small Adriatic plate was decoupled from Africa along a transform shear zone and began to rotate counter-clockwise. On platforms carbonate deposition continued throughout Jurassic times. However, rift-induced further break-up of platforms and their post-rift subsidence led to the establishment of additional deep basins characterized by carbonate, shaly and cherty sediments.

Cretaceous-Eocene Subduction Stage (Figs. 3b and 3c)

Subduction processes commenced in the Central Mediterranean domain already during the Late Jurassic onset of closure of the Vardar Ocean. During the Cretaceous, rapid opening of the North Atlantic caused rotation of the Adriatic block and the initiation of a transform subduction zone along its northern margin (Ziegler et al., this volume). With the Senonian onset of counter-clockwise convergence of Africa-Arabia with Europe, suduction zones rapidly propagated into the Western Mediterranean. Gradual closure of the Ligurian-Piedmont-Penninic Ocean went hand in hand with progressive uplift of the Alpine and Apennine ranges and the shedding of flysch into remnant oceanic basins and gradually evolving foreland basins.

Oligocene to Recent Continental Collision Stage (Figs. 3c and 3d)

Following subduction of the Ligurian-Piedmont-Penninic Ocean, the Adriatic plate was framed by the continent-to-continent collisional Dinarid, Alpine and Apennine orogens. Its passive margin sedimentary prisms were overridden by nappes, consisting of oceanic crustal slices and their deep-water sedimentary cover, and were themselves detached along basal, mostly evaporitic, levels. Thrust-loaded subsidence of foredeep basins, paralleling the evolving Alps and Apennines, provided accommodation space for thick syn-orogenic flysch series. Progressive migration of the thrustbelt-foredeep systems towards the foreland was accompanied by drowning out of the latter and the deposition of thick clastic wedges, consisting of flysch series grading upwards into shallow water and partly alluvial deposits. Kinematic considerations suggest, that post-Tortonian compressional features developing along the external front of the Apennine, are the result of active thrusting, combined with passive subsidence of the foreland lithosphere (Patacca and Scandone, 1989; Scandone et al., 1992).

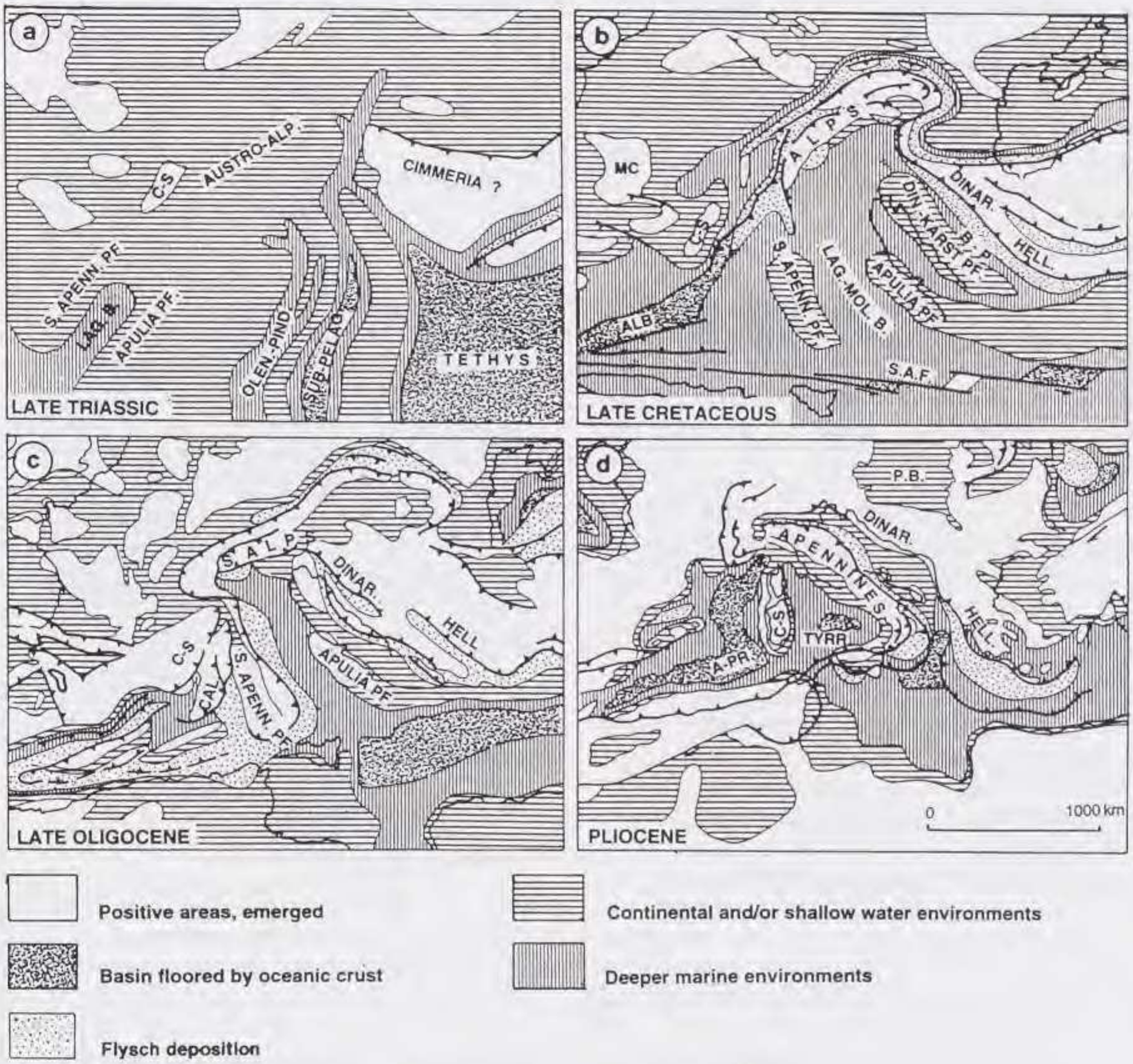


FIG. 3. Paleogeographic-geodynamic maps (general framework simplified after Ziegler (1988) and modified for the central Mediterranean area). LAG. B: Lagonegro Basin; C-S: Corsica-Sardinia block; OLEN.-PIND: Olenos-Pindus Basin; SUB PELAG: Sub Pelagonian basin; MC: Central Massif; S.A.F: South Anatolian Fault Zone; ALB: Alboran (Liguria-Piedmont) ocean; DINAR: Dinarides; HELL: Hellenides; DIN.-KARST PF: Dinarides-Karst Platform; APULIA PF: Apulia Platform; LAG.-MOL: Lagonegro-Molise Basin; S. APENN. PF: S Apennine Platform; P.B: Pannonian Basin, TYRR: Tyrrhenian Basin; A-PR: Algero-Provençal Basin.

From Late Miocene times onward, the Tyrrhenian and Peri-Tyrrhenian areas were subjected to extension, causing their collapse and the subsidence of the episutural Algero-Provençal and Tyrrhenian system of basins.

During Late Miocene times, temporary isolation of the Mediterranean Sea (Hsü et al., 1977) resulted in an evaporation-induced lowering of the sea-level and the widespread deposition of Messinian evaporites. As a consequence of earliest Pliocene re-opening of communications with the Atlantic Ocean, normal sea-levels and salinities were established again.

According to prevailing subsidence mechanisms, the sedimentary successions of the foreland, as well as those involved in the Apennine and South-Alpine thrustbelts, can be subdivided into the following tectono-stratigraphic sequences (Fig. 4):

(1) the **pre-rift and syn-rift sequence** commences with Permo-Triassic continental clastics, resting on Hercynian basement, which include Triassic evaporites and/or shales and carbonates, deposited prior to the regional Tethys transgression. It contiues with shallow marine carbonate banks which, during Early to Middle Jurassic times, may evolve into deeper water basins where shales and cherts are associated with carbonates,

(2) the **passive margin sequence** ranges in age from Middle Jurassic to Late Cretaceous and consists of shallow water carbonate banks separated by wide, deeper water basins. Local pelagic carbonate platforms, characterized by frequently condensed sequences, hardgrounds, episodes of submarine erosion and stratigraphic gaps, are present (Santantonio, 1994),

(3) the **foredeep sequence** generally commences with shales to shaly carbonate deposits, which reflect rapid flexural subsidence of the foreland to considerable water-depths. This initial transgressive unit grades upwards into flysch, supplied by clastics derived from the rising orogens. Depending on clastic supply and subsidence rates, flysch series can grade upwards into shallow marine and continental sediments (e.g. Po Plain Pliocene-Quaternary foredeep). As the axes of foredeeps migrated in time towards the foreland, facies boundaries are time transgressive. Moreover, synsedimentary compressional deformation of the proximal parts of foredeep basins, causing the development of sea-floor topographic anomalies, influenced the distribution of turbiditic sands; these accumulated preferentially in synclinal areas whereas anticlinal ridges wre characterized by hemipelagic sediments (Pieri and Mattavelli, 1986).

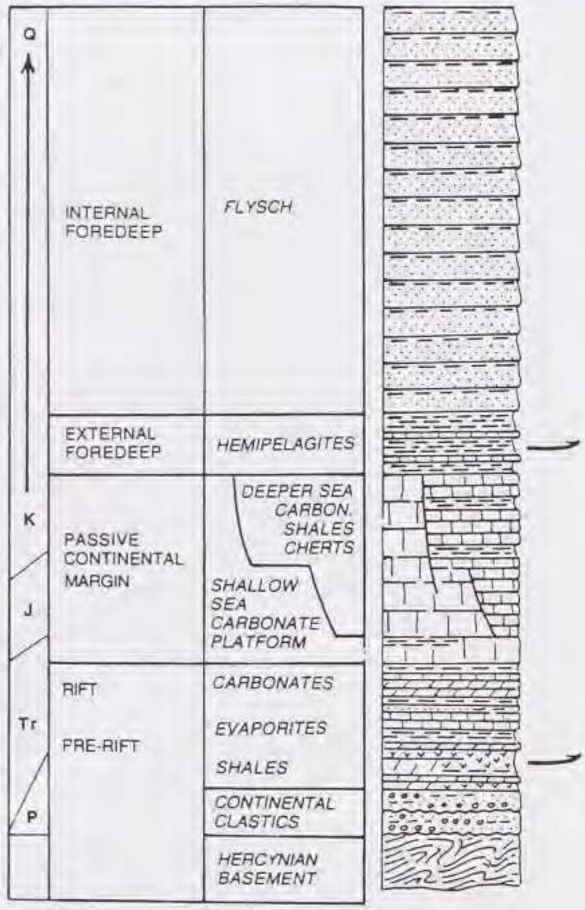


FIG. 4. General sedimentary succession of the Adria continental margin. Flysch deposition is strongly heterochronous. Arrows correspond to main detachment levels.

In areas corresponding to peripheral bulges (e.g. large parts of Puglia region, Fig. 5), the foreland is not incorporated into the foredeep basin and the entire Cenozoic sequence consists of discontinuous shallow-water carbonates.

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

The main structural units of Italy are the Alpine and Apennine fold- and thrustbelts, the foreland of which corresponds to the stable continental block of the Po Plain and Adriatic Sea. To the South, the Apennine finds its continuation in the Calabrian-Sicily arc. Its foreland is formed by the oceanic Ionian Sea and the continental Pelagian Shelf (Fig. 5). The structural cross-sections given in Enclosures 1-3 show that the autochthonous foreland crust extends up to 100 km under the Apennine thrustbelt and as much as 70 km beneath the Southern Alps.

The structural style and configuration of the Alpine and Apennine fold- and thrustbelts are controlled by the thickness and rheological composition of the sedimentary sequences involved in them, as well as by the geometry of the Mesozoic basins out of which they evolved. During the evolution of the Alps and Apennines, many of the main extensional faults, controlling the distribution of Mesozoic platforms and basins, were compressionally reactivated and often developed into main thrust faults (e.g. boundary between Northern and Southern Apennine). Correspondingly, the different tectono-stratigraphic units of these orogenic belts conform, with a few exceptions, to Mesozoic palaeogeographic zones.

Southern Alps

In the Southern Alps, the following four structural zones are distinguished (Doglioni and Bosellini, 1987; Consiglio Nazionale delle Ricerche, 1989):

(1) the South-Alpine **Lombardy fold and thrust arc** developed during the Late Cretaceous and Late Miocene out of a Triassic rifted basin (see Ziegler et al., this volume). Its external units emerged during the Messinian low-stand in sea-level and are sealed by undeformed Plio-Pleistocene sediments, attaining thicknesses of up to 2.5 km (Encl. 1, sect. 1)

(2) the **Verona (Lessini Mts.)** area was not affected by Alpine deformations and represents the outcropping part of the Po Plain foreland which is bounded to the Northwest by the frontal elements of Lombardy thrust belt and to the Northeast by the Schio transcurrent fault

(3) the WSW-ENE trending **Veneto folds and thrusts** were activated during the Miocene and are tectonically still active. Their southern front corresponds to the morphological boundary between the pre-Alps and the Veneto Plain (Encl. 1, sect.2)

(4) the NW-SE striking **Dinaric folds and thrusts** find their on-strike prolongation in the Dinarides and the Hellenides. Whereas crustal shortening in the northern Dinarides terminated in Mid-Miocene times, their southern parts and the Hellenides are still active to day.

The stratigraphic succession of the Southern Alps reflects the development of the northern Adria continental shelf. Late Permian to Early Triassic continental clastics and local evaporites are covered by Middle to Late Triassic carbonate platforms and intervening anoxic basins. During Jurassic times, deep water basins developed in the Lombardy and western Veneto areas whereas the Verona zone was occupied by a pelagic carbonate platform. In the East-Veneto, and the Dinaric zone, shallow-water carbonate platforms persisted into Late Cretaceous times. In the Lombardy Basin, Late Cretaceous and Oligo-Miocene flysch, records the gradual uplift of the Southern Alps

FIG. 5. Italy: main structural units. Traces of sections iven in Encl. 1, 2 and 3.

(Ziegler et al., this volume), whereas in the Veneto and Dinaric zones flysch sedimentation commenced only in the Eocene. In contrast, Paleogene-Miocene strata are represented on the Verona High by shallow-water carbonates.

Apennine

The Apennine, which evolved on the western passive margin of the Adriatic plate, can be subdivided into three main sectors which are bounded by major thrust fronts. The internal parts of the Apennine were affected by Neogene extensional faults related to the opening of the Tyrrhenian Sea.

In the area of the **Northern Apennine**, the Mesozoic continental shelf was characterized by a relatively uniform stratigraphic succession, consisting of a Late Triassic continental clastic and evaporitic-dolomitic series, earliest Jurassic shallow-water carbonates and mid-Early Jurassic to Paleogene deep-water carbonates. The transition to flysch accumulation occurred on the distal shelf, corresponding to the internal Apenninic unit, during the Late Oligocene and progressed during the Miocene and Pliocene into the domain, now represented by the northeastern and eastern external Apenninic units and ultimately into the area of the present foredeep basins.

During the Alpine orogenic cycle, these sedimentary sequences were detached from their basement at the level of the Late Triassic Burano evaporites (Encl. 1, sect. 3). In the Emilia and Tuscany regions, the internal parts of the Adria passive margin successions are widely covered by the Ligurides nappes which consist of obducted ophiolitic fragments and deep-water sediments, deposited in the Liguria-Piedmont oceanic basin.

The **Southern Apennine** consists of four tectono-stratigraphic units which differ in the composition of their Mesozoic series. Each unit corresponds to a major nappe. During the stacking of these nappes, extensive detachment of flysch units from their carbonate substratum occurred. In comparison with the Northern Apennine, the southern one is characterized by a more complex architecture and a greater amount of shortening (Encls. 2 and 3, sect. 4, 5, 6).

The tectonically upper-most, and therefore the most internal unit, is composed of flysch sequences attributed to the possibly oceanic Ligurides domain. The next lower unit, corresponding to the South-Apennine platform, consists of Mesozoic-Paleocene platform carbonates, Early Miocene carbonates and Middle Miocene flysch. It overlays a unit which is derived from the Lagonegro trough and consists of Mesozoic-Paleogene-Lower Miocene calcareous, cherty and shaly sequences, followed by Middle Miocene quartzarenitic flysch. The lower-most unit, and therefore the most external one, is analogous to that of the Puglia foreland and is characterized by thick platform carbonates ranging in age from Jurassic to Cretaceous, which are unconformably covered by thin and discontinuous Paleogene and Miocene shallow water carbonates. The Cretaceous-Paleogene sequence may however change westward to deeper water carbonate sediments.

The frontal thrust sheets of the Southern Apennine involve allochthonous Miocene flysch and fill the foredeep which is limited to the N-E by the Puglia foreland.

The southern-most sector of the Apennine, corresponding to the Calabrian arc, is characterized by the internal Calabria-Peloritani nappes which involves Hercynian basement; this nappe is possibly derived from the northwestern margin of the Alboran-Ligurian Ocean.

Current palaeogeographic reconstructions place the deep-water Lagonegro Basin between the Apulian and South-Apennine carbonate platforms (Pieri, 1966; D'Argenio et al., 1973; Mostardini and Merlini, 1988). An alternate interpretation proposes that the Lagonegro Basin was located to the west of the South-Apennine platform, was thrusted during the Langhian-Tortonian over this platform and was enveloped during the Messinian-Pliocene by the South-Apennine nappe (Marsella et al., 1992).

The **Sicily-Apennine** occupies the northern and central parts of the island and links up through the the Sicily Channel with the Maghrebides of North Africa (Encl. 3, section 7). The stratigraphy of the external units of the Sicily Apennine and their tectonic relationship with the autochthonous foreland are still poorly known. Such units may occur beneath the more internal Imerese and Panormide nappes and may be characterized by a similar sedimentary succession as seen in the foreland of southeastern Sicily. The Imerese nappe consists of sedimentary sequences which are similar to the Lagonegro unit of the Southern Apennine. The Panormide units consist of Late Triassic to Early Cretaceous shallow-water carbonates. The most internal units, representing a continuation of the Ligurides and the Calabria-Peloritani nappes, occur in northeastern Sicily.

In general, the tectono-stratigraphic units of the Southern Apennine can be correlated with those of the Sicily-Apennine. The most external units of the Sicily-Apennine consist of Miocene flysch and post-flysch clastic successions which are detached from their substratum and fill a Pliocene-Quaternary foredeep.

Foreland of the Southern Alps and Apennine

The Mesozoic-Paleogene-Miocene series of the foreland in the subsurface of the Po and Veneto plains correlate with those of the external units of the Southern Alps (Pieri, 1984). In the northeastern Adriatic Sea, the Dinaric succession is recognized, whilst from Rimini to Pescara and in the South-Adriatic the composition of the foreland sequences does not significantly differ from those of the external Northern Apeninne. In this area, flysch sedimentation commenced in a very broad foreland basin during the Pliocene and grades upwards into Pleistocene deltaic series.

South of Pescara, the Apennine foredeep basin is separated from the Adriatic Basin by the Puglia (Apulian) Platform which can be regarded as a peripheral bulge that was affected by Plio-Pleistocene normal faults. According to the results of the deep wells Puglia-1 (TD 7070 m) and Gargano-1 (TD 4853 m), this platform consists of thick Cretaceous and Jurassic shallow-water carbonates, Late Triassic Burano anhydrites and dolomites and Middle to Early Triassic and Permian carbonates and clastics.

The Sicily foreland succession consists of Late Triassic-Early Jurassic shallow-water carbonates and interspersed deeper-water troughs in which the organic-rich carbonates and shales of Noto and Streppenosa Formations were deposited, representing important source-rocks. Middle Jurassic to Eocene series consist of deep-water cherty limestones. These are overlain by calcareous-marly Oligocene to Miocene strata. Late Cretaceous to Late Miocene shallow-water deposits are only known from the Siracusa area. During the Neogene the Pelagian Shelf was transsected by the northwest striking Pantelleria rift system.

SOURCE-ROCK HABITAT

Middle and Late Triassic rift-induced subsidence of often limited inter- and intra-platform deeper-water troughs, characterized by poorly oxygenized, stagnant bottom waters, was favourable for the deposition and preservation of organic-rich shales and carbonates and thus the accumulation of oil-prone source-rocks. Similar conditions developed also in intra-platform subtidal ponds and lagoons. About 90% of the oil tapped in fields so far discovered has been generated by Middle and Late Triassic source-rocks (Mattavelli and Novelli, 1990). A similar setting is indicated for the Late Triassic and Early Jurassic Noto and Streppenosa source-rocks of Sicily.

During Middle and Late Jurassic and Cretaceous sea-floor spreading and ocean subduction stage, several anoxic events occurred, such as the one related to the regionally recognized basal Turonian Bonarelli Bed (Farrimond et al., 1990). Due to limited thickness, these organic-rich intervals cannot be regarded as effective source-rocks. However, in the Southern Apennine an effective Cretaceous source-rock (unknown in outcrops), may have generated the oils trapped in the Costa Molina and related fields (Fig. 1).

During the Cenozoic collisional stage, no euxinic enviromments developed. Nevertheless, preservation of mainly terrestrial organic matter in the distal parts of Neogene turbiditic fans favoured the generation of light oils in the Apennine thrust belt and bacterial gas in the foredeep (Mattavelli and Novelli, 1987; Mattavelli et al., 1992a).

Sedimentological and geochemical characteristics of Italian source-rocks have been extensively analyzed and discussed (Pieri and Mattavelli, 1986; Mattavelli and Novelli, 1987, 1988, 1990; Brosse et al., 1988; Stefani and Burchell, 1990, 1993; Zappaterra, 1994). Here we discuss only the geochemical characteristics of source-rocks which play an important role in the hydrocarbon habitat of Italy.

Mesozoic Source-Rocks of the Southern Alps and Po Plain

The most important source-rocks are the Middle Triassic Besano (Grenzbitumen zone) and the Meride formations which crop out in the western part of the Southern Alps near the border between Italy and Switzerland (Fig. 6).

The up to 16 m thick Besano Formation is characterized by alternating laminated dolomites and black shales. It is an excellent source-rock with an average TOC content of 12% and maximum values of 40% (Fig. 7a). The kerogen, mainly amorphous organic matter (75%, Fig. 7b), has a high generation potential averaging about 60 kg HC/t and ranging up to 200 kg HC/t.

The overlying 300 m thick Meride Formation consists to 83% of limestones and to 17% of argillaceous limestones, marls and back shales and has an average TOC content of only 0.65%. Limestones may be considered as lean source-rocks, whereas argillaceous intercalations yield average TOC values of 2.4%. The organic matter consists to 75% of land-plant material.

The Besano and Meride Formations are the source for oils reservoired in the deep Mesozoic carbonates (>6000 m) of the major Villafortuna-Trecate field. In the past the role played by Middle Triassic source-rocks in the hydrocarbon habitats of the Po Plain and the Southern Alps was underestimated. Stefani and Burchell (1993) considered the clay-rich Rhaetian series as the main oil contributors. However, it is now realized that the Besano and Meride Formations are the most important source-rocks of Northern Italy.

These formations were deposited in the Lombardy intra-carbonate platform basin, which covers about 1200 km^2 and subsided in response to Late Anisian-Ladinian crustal extension, accompanied by widespread volcanic activity (Bernasconi and Riva, 1993; Ziegler et al., this volume). At depositional sequence scales, rapid increases in water-depths, either due to regional transgressions or accelerated tectonic subsidence rates, are often associated with enrichment in organic matter (Creaney and Passey, 1993; Stefani and Burchell, 1990; Katz and Pratt, 1993). Ample supply in land-derived nutrients inducing phytoplankton blooms, led to the development of eutrophic conditions and a reduced level in carbonate production. Accumulation of the highly organic Besano shales reflects severe anoxic bottom waters and a reduced influx of carbonates from adjacent platforms. In contrast, the Meride Formation, forming part of the same depositional sequence (Gaetani et al., 1991), reflects increased carbonate production on platforms from which frequent turbidity currents transported lime-muds into the Lombardy basins, thus causing dilution of the organic matter.

Late Triassic increased crustal extension caused disintegration of the widespread Norian carbonate platform into a system of highs and intervening troughs in which micritic limestones were deposited under anoxic conditions (Aralalta Group). These are covered by transgressive, argillaceous Rhaetian series, consisting of the basal Riva di Solto Shale and the upper Zu Limestone sequence (Fig. 7c Stefani and Burchell, 1990). The Riva di Solto Shales vary in thickness from 2 km in the Lake Iseo depocentre to less than 100 m on local palaeo-highs; lateral facies and thickness changes are related to syndepositional tectonics (Pieri and Mattavelli, 1986).

In outcrops, Late Triassic sediments are generally over-mature, except on long-lived palaeo-highs (see Table 1). Basal Rhaetian argillaceous deposits have average residual TOC content of 2-3% ranging up to maxima of 5%. A less important increase in TOC is observed in the upper parts of the Zu Limestone; samples of immature black shales on palaeo-highs yielded TOC values of 0.7-1.5% and have a generation potential of 1-3 kg HC/t. Both Rhaetian anoxic events correlate with transgressive episodes and are characterized by predominantly land-plant derived organic matter. As such they are gas- and gas-condensate prone source-rocks (Fig. 7b), as indicated by the Malossa gas-condensate field (GOR 1000; Mattavelli and Margarucci, 1992).

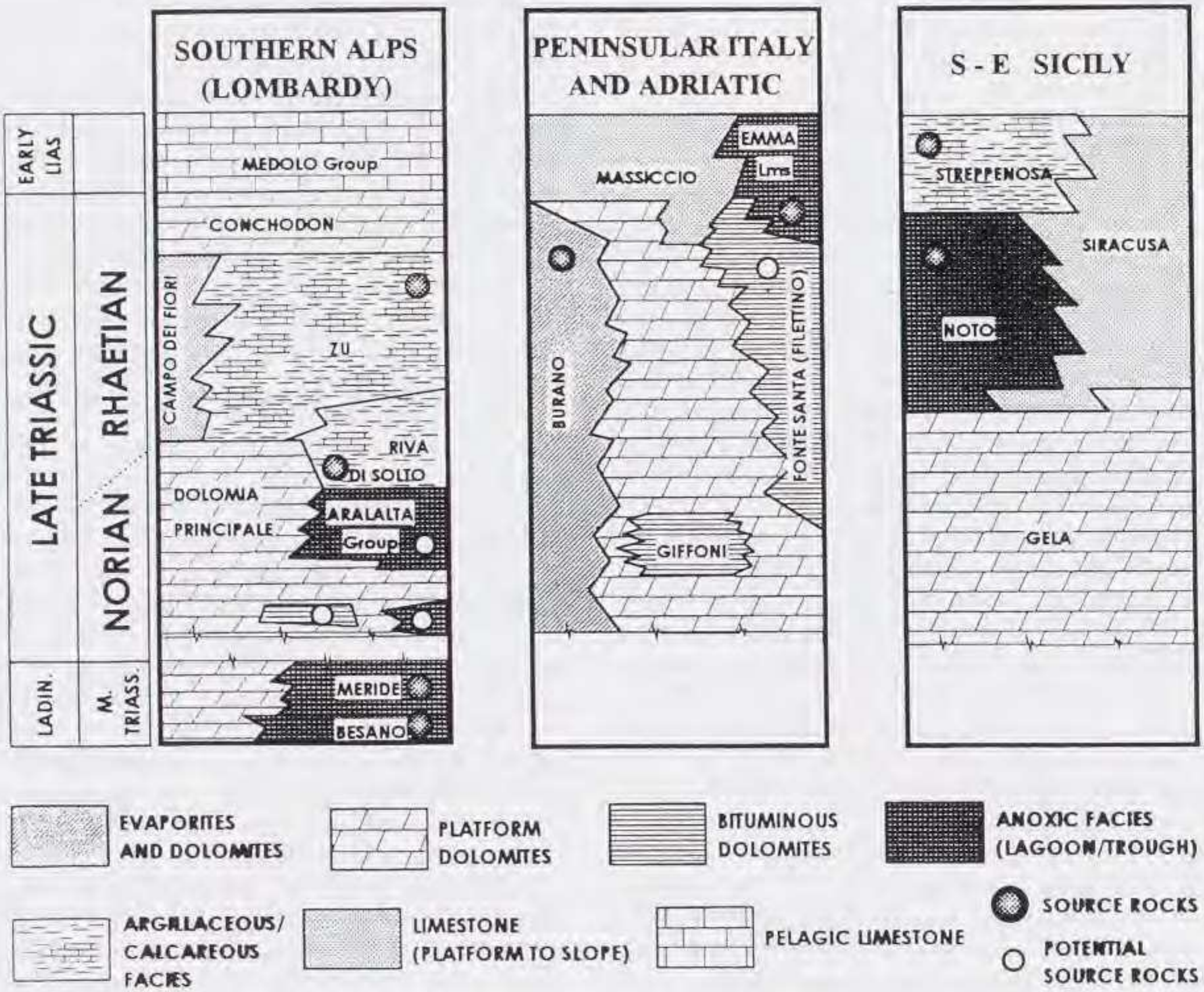


FIG. 6. Middle-Late Triassic, Early Lias stratigraphic charts of Southern Alps, Peninsular Italy - Adriatic and Southeastern Sicily. Relationships between the main litostratigraphic units and occurrence of Triassic effective and potential source rocks.

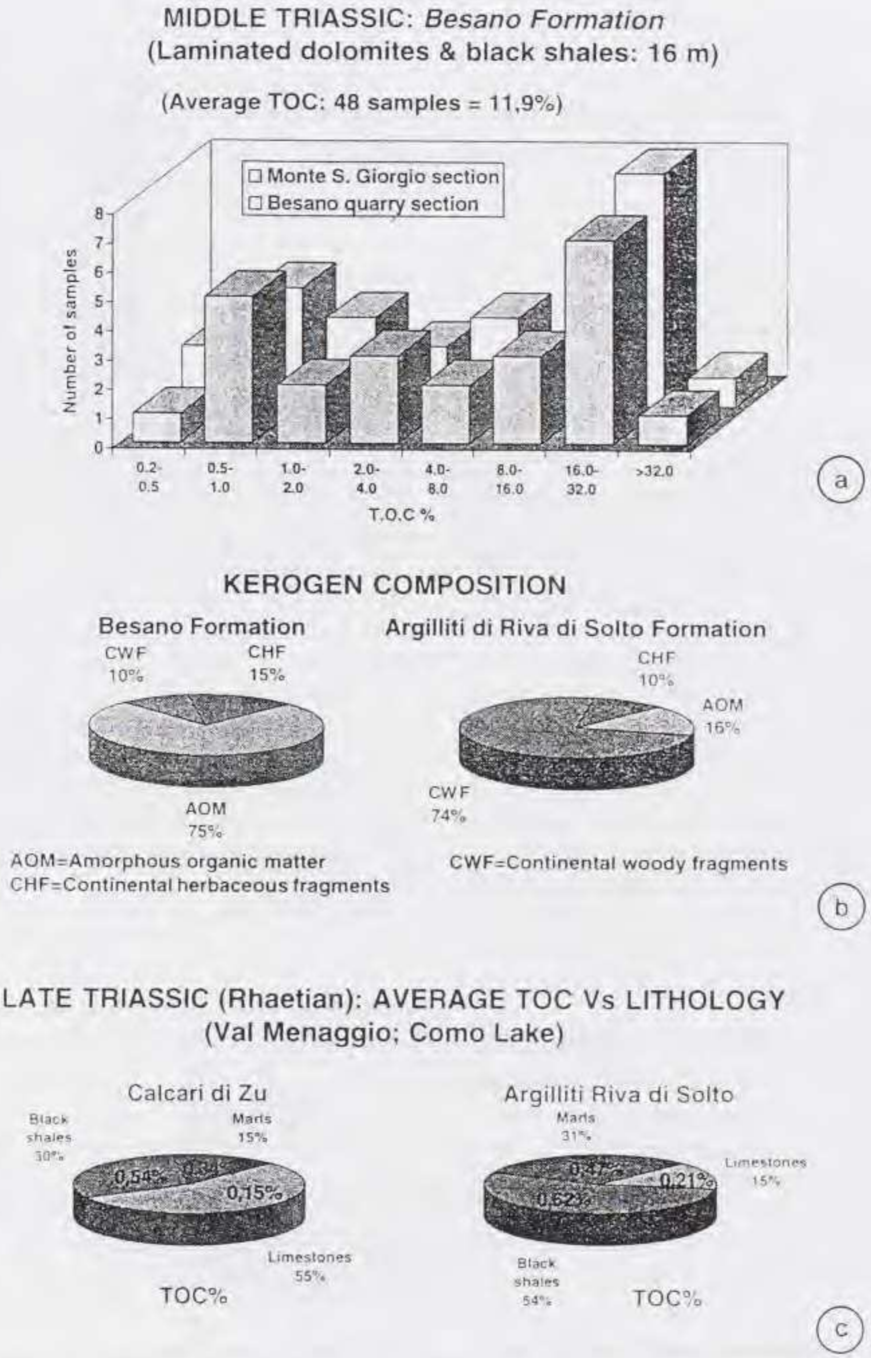


FIG. 7. a: Middle Triassic Besano Fm, S Alps. TOC vs number of samples of two significant outcrops in NW Lombardy.
b: Triassic source rocks in Southern Alps, Lombardy. kerogen composition of Besano (Middle Triassic), and Riva di Solto (Late Triassic) Fms. Amorphous organic matter prevails in Besano Fm, while continental woody fragments dominate in the Riva di Solto Fm.
c: Late Triassic Rhaetian sources in Southern Alps. Average TOC vs lithology in Zu and Riva di Solto Fms. Shale and marls are effective source rocks, while the limestones are mostly lean source rocks.

In a broader context, frequent occurrences of anoxic carbonates and shales have been reported from the Hauptdolomite platform of the Northern Alps (Müller-Jungbluth, 1968; Koster et al., 1988) and the time-equivalent Dolomia Principale of the Southern Alps (Jadoul, 1985).

Mesozoic Source-Rocks of the Southern Apennines and Adriatic Foreland

Reconstruction of the Late Triassic source-rock habitat in the Southern Apennine is hampered by the paucity of outcrops, an apparently complex palaeogeographic setting and the Neogene nappe structures (Ciarapica et al., 1987).

In the Simbruini Mts. (Filettino, 60 km E of Rome), Late Triassic platform carbonates change laterally to alternating dolomites, laminated dolomites containing very thin layers of marls and anoxic black shales. The distribution of organic matter is extremely heterogeneous. TOC values of gray dolomites are <0.1%, range in laminated dolomites between 0.4 and 3.2% and are >45% in centimetre thick shale layers (Fig. 8a). The kerogen is immature (R_0=0.4%), is predominantly of marine origin (Fig. 8b) and has a high HI (600-800 mg HC/g TOC). The average generation potential is 2 kg HC/t and exceeds 200 kg HC/t in shales.

In the Picentini Mts (Giffoni, 60 km SE of Naples), Late Triassic organic shales and laminated dolomites yielded a rich ichtyofauna (Boni et al., 1990). Organic-rich layers have an average TOC content of 4.5% and a generation potential of up to 572 mg HC/g TOC; the kerogen is mainly algal in origin. Sedimentological criteria indicate that this succession was deposited in a relatively shallow, subtidal lagoonal trough, surrounded by extensive carbonate platforms.

Similar anoxic Late Triassic successions are known from the Gran Sasso Range. This basin may extend to the northeast into the off-shore where the Late Triassic Emma limestone sourced the Gianna oil accumulation (Adamoli et al., 1990).

Evaporitic euxinic environments, favourable to preservation of organic matter, developed also during the deposition of the Burano Formation, as indicated by the correlation of Adriatic oils with organic shales intercalated with the Burano evaporites (Paulucci et al., 1988; Mattavelli and Novelli, 1990). However, as only few wells penetrated the Burano Formation, the geometry and areal extent of this hydrocarbon generating basin is largely unknown.

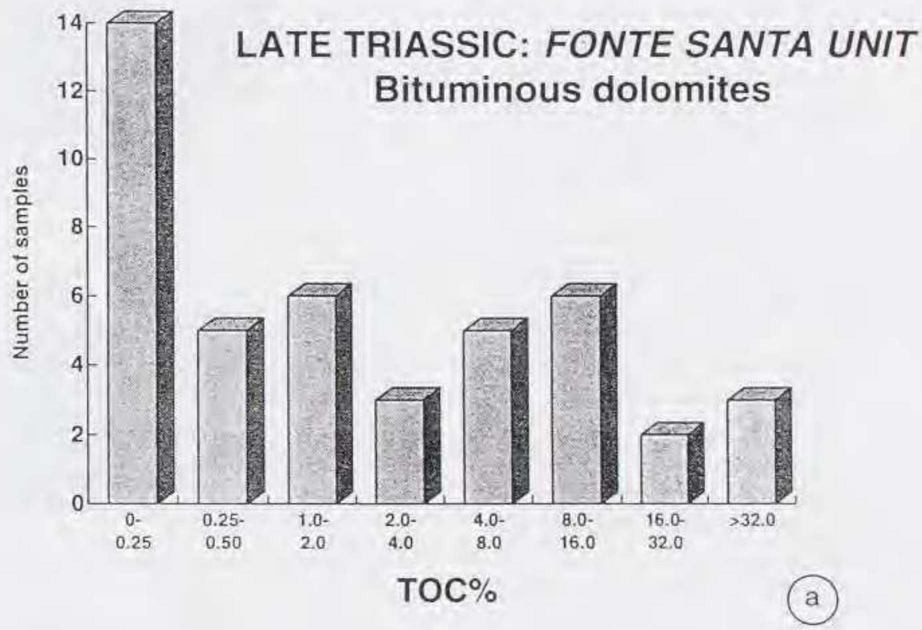
In conclusion, the area of the Southern Apennine and the Adriatic foreland was occupied during Late Triassic times by an extensive tidal carbonate-evaporite platform in which discontinuous euxinic sub-basins, extremely variable in size and shape, developed. These sub-basins can be subdivided into lagoonal troughs, over which platform carbonates prograded (e.g. Giffoni Basin), and rifted lagoonal troughs which later evolved into deeper water basins (e.g. Emma Basin) (Fig. 6; Zappaterra, 1994).

Mesozoic Source-Rocks of the Southeast Sicily Foreland

Geochemical data indicate that the heavy oil accumulations of southeastern Sicily (e.g. Gela, Ragusa, Perla, Prezioso, Vega fields) were charged with hydrocarbons generated by the carbonate-dominated Rhaetian Noto and the shaly Hettangian

Location	Average TOC		Ro %
	Riva di Solto Sh	Zu Lst	
Val Menaggio (W of Como L.)	0.52	0.45	1.0 - 2.14
Val Seriana (N of Bergamo)	0.50	0.25	1.38 - 3.28

TABLE 1



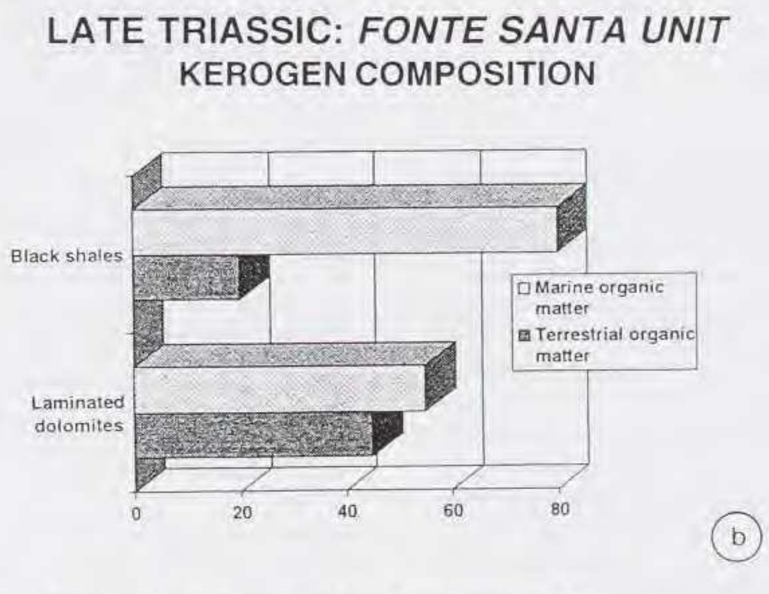


FIG. 8. Late Triassic Fonte Santa Unit, Southern Apennine (Filettino).
a: TOC values distribution. The richest organic matter layers are the thin argillaceous intercalations in the "Bituminous Dolomites".
b: Kerogen composition.

Streppenosa formations; the latter attains in depocentres thicknesses of up to 3000 m (Fig. 6; Pieri and Mattavelli, 1986; Mattavelli and Novelli, 1990). Sedimentological evidence suggests that these source-rock successions, only known from well data, were deposited in limited tensional/transtensional basins which subsided in a carbonate platform (Brosse et al., 1988; Catalano and D'Argenio, 1983).

The Noto Formation exhibits an average TOC content of around 1%; values in the 3-10% range were obtained from marl and black-shale intercalations (Brosse et al., 1988). Its generation potential ranges from 3 to 5 kg HC/t. The kerogen is mainly type II (Novelli et al., 1988) and has an HI of up to 900 mg/g TOC (Fig. 9). On the other hand, the Streppenosa Formation is characterized by a lower TOC content (average 0.35%) and generation potential (0.5 kg HC/t) and by type III kerogen consisting mainly of woody material.

As observed in the Southern Alps and in Northwest Europe, Rhaetian and Hettangian source-rocks were deposited during cycles of rising sea-levels (Creaney and Passey, 1993; Ziegler, 1990).

Cenozoic Source Rocks

In the evolving Cenozoic foreland basins of the Southern Alps and Apennines, siliciclastic turbiditic series attain thicknesses of several kilometres. In these rapidly subsiding basins, the floor of which was affected by synsedimentary compressional deformations (Pieri and Mattavelli, 1986), conditions for development of anoxic conditions were not favourable. However, predominantly land-plant derived organic matter was preserved, mainly in in the distal parts of siliciclastic turbidites, due to relatively high sedimentation rates, preventing its oxydation. In contrast, very high sedimentation rates, characterizing the proximal parts of submarine fans, apparently account for dilution of organic matter (Mosca and Dalla, 1993).

Geochemical analyses demonstrate that the turbiditic Langhian-Tortonian Marnoso-arenacea Formation has an average TOC content of 0.68%

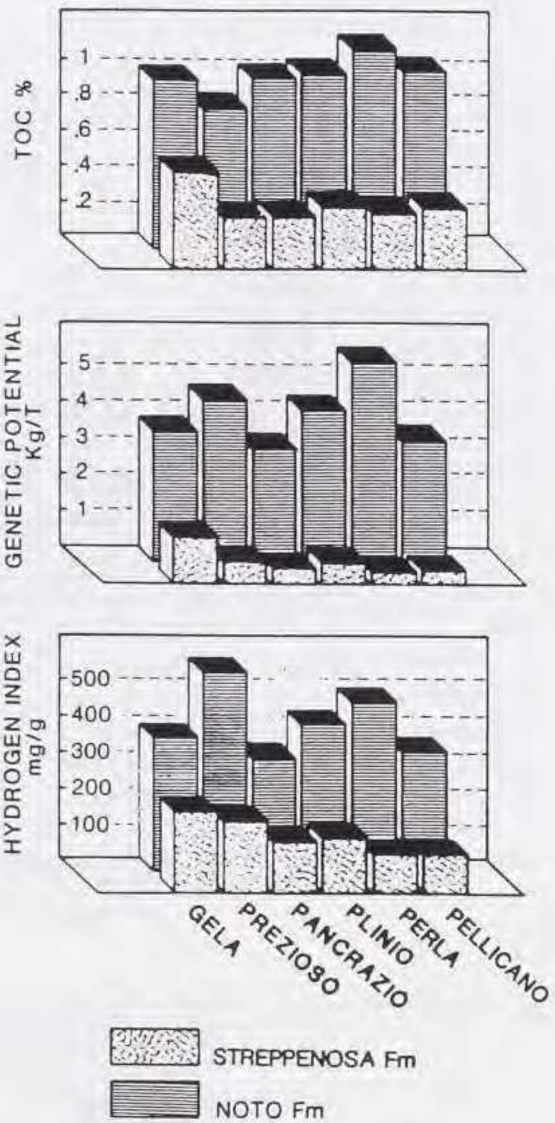


FIG. 9. Late Triassic-Early Lias Noto-Streppenosa Fms, Sicily. Average TOC and Rock-Eval values relevant to some key wells of South Sicily offshore. The Noto Fm is the effective source rock, while Streppenosa plays a minor role as co-source.

and that the kerogen consists to 80% of land-plant derived matter (Riva et al., 1986). This formation generated the light oils occurring in the external parts of the Northern Apennine (e.g. Cortemaggiore field) (Fig. 10; Riva et al., 1986). Similarly, isotopic data and molecular parameters suggest that the Tertiary flysch of the Southern Apennine generated the light oils contained in e.g. the Castel-

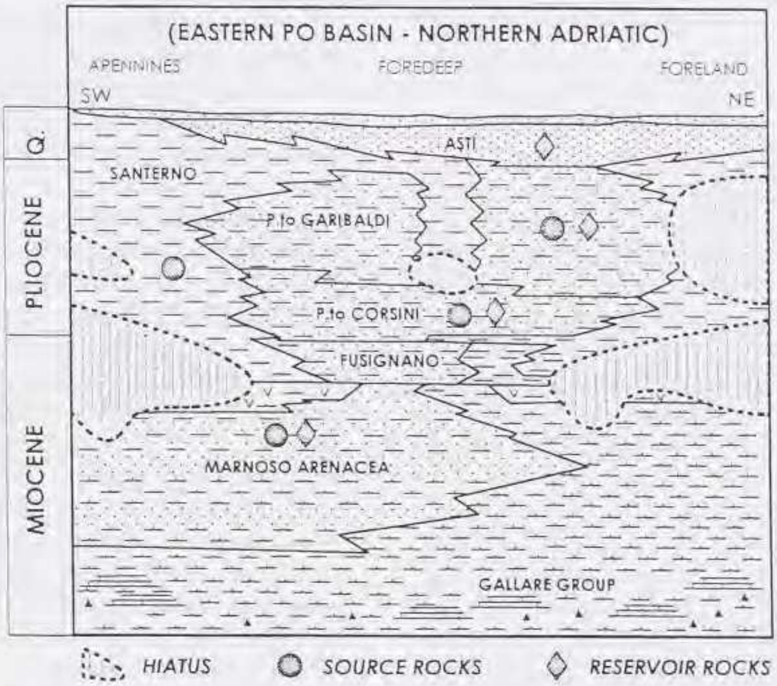


FIG. 10. Late Neogene stratigraphic chart of Eastern Po Plain and North Adriatic. Relationships between the Neogene lithostratigraphic units and main reservoirs and gas prone source rocks.

pagano and Benevento fields (Mattavelli and Novelli, 1990). Tortonian sand-shale successions of the Veneto, the Southern Adriatic and Western Sicily contain only biogenic gas.

In the thick Plio-Pleistocene turbiditic series of the Po Plain and the Northern Adriatic foredeep, enrichment in organic matter occurs mainly in the shaly distal basin plain deposits of highly efficient turbidites (Mutti, 1985). Organic-rich layers can have a TOC content of about 0.7% of which 85% is land-plant derived. Detailed analyses of core material show that the TOC content of re-sedimented clays is 2 to 5 times greater than that of hemipelagic ones (Mattavelli et al., 1992b). The huge volume of Plio-Pleistocene turbiditic series (several thousands of km^3), containing mainly allochthonous land-plant derived organic matter, represents Italy's main source-rock. 80% of Italy's ultimate recoverable gas reserves, corresponding to 2/3 of its entire hydrocarbon resources, consist of biogenic gas trapped in the Northern Apennine foredeep.

PETROLEUM SYSTEMS

In the following we summarize the different petroleum systems of Italy. These are outlined in Fig. 11.

Mesozoic Besano-Meride System, Western Po Plain

In the subsurface of the Po Plain, the South-Alpine and North-Apennine thrust fronts delimit their common foreland (Fig. 5). As Mesozoic carbonate series were virtually unaffected by Tertiary compression, Triassic-Jurassic extensional structures are preserved. Gravity data indicate the presence of a basement high southwest of Milano (Cassano et al., 1986) over which Mesozoic series decrease in thickness to a few hundred meters.

FIG. 11. Approximate geographic distribution of Italian Petroleum Systems.

This high is buried beneath 4000 to 6000 m of Cenozoic strata.

On this palaeo-high, the Gaggiano (1982) and Villafortuna-Trecate (1984) light oil fields were discovered; the latter is one of the largest on-shore oil fields of Europe and has URR of $20 \cdot 10^6$ t ($150 \cdot 10^6$ bbl). Both fields are contained in block-faulted structures which were charged by vertical migration from Middle Triassic source-rocks. The reservoir of the Gaggiano field is located at a depth of 4600 m and consists of two dolomitic layers in the top part of the Meride Formation, providing for a limited trap volume. The reservoir of the Villafortuna-Trecate field is formed by Middle Upper Triassic dolomites, located at depths from 5500 to 6300 m. Both accumulations are sealed by Mesozoic pelagic limestones which are capped by thick Tertiary shaly flysch (Bongiorni, 1987; Novelli et al., 1987; Schlumberger, 1987).

These light oil fields (Gaggiano 36° API, Villafortuna-Trecate 43° API; 0.2% sulfur content) are significantly overpressured (about twice as high as hydrostatic). Overpressure developed in the impervious strata of Oligocene-Miocene sediments during the Neogene rapid subsidence of the Po foreland basin (Novelli et al., 1987). These pressures were subsequently transmitted to the underlying Mesozoic carbonates, the hydraulic continuity of which was disrupted by Tertiary compressive tectonics.

Subsidence analyses indicate that Triassic source-rocks attained maturity for oil generation only during Pliocene-Pleistocene times. The late generation of petroleum may be partly related to the build-up overpressures that retarded hydrocarbon expulsion (Chiaramonte and Novelli, 1986; Mattavelli and Novelli, 1988; Hao Fang et al., 1995).

The genetic potential of source rocks in Gaggiano field exhibits a SPI value (SPI=Source Potential Index, Demaison and Huizinga, 1991) of 2 t HC/m^2 while in the outcrops of the Southern Alps their value is around 4 t HC/m^2. Consequently, a low charge factor may have to be assigned to Besano-Meride source rocks, following the genetic classification of Demaison and Huizinga. Furthermore, the lack of significant oil occurrences in Cenozoic series indicates that the pressures at the top of these light oil accumulations did not exceed the entry pressure of their seal (Hunt, 1990).

In conclusion, the Besano-Meride petroleum system is characterized by low a charge factor (i.e. hydrocarbon yeld), vertical migration paths and good a integrity of the seal

Mesozoic Riva Di Solto System of Southern Alps

In 1973 the Malossa gas-condensate field was discovered in the external parts of the Lombardy thrustbelt which are buried under up to 2 km thick Plio-Pleistocene series of the Po Plain (Encl. 1, section 1). Subsequently additional marginal gas-condensate accumulations, such as Seregna and San Bartolomeo, were discovered in the vicinity of Malossa (Errico et al., 1980; Mattavelli and Margarucci, 1992).

The Malossa field is contained in a northwest striking thrust-anticline which evolved during the Miocene deformation of the Lombardian thrustbelt by reactivation of a Late Triassic extensional fault block. Such northerly trending extensional structures were separated by intervening depocentres in which the Rhaetian Riva di Solto and Zu source-rocks were deposited (Fig. 4-1; Pieri and Mattavelli, 1986; Bertotti et al., 1993). These have been identified as the sources of the hydrocarbons reservoired in the over-pressured, fractured low-porosity (3%) Norian and Early Jurassic carbonates of the Malossa field; from these gas migrated into fractured younger Jurassic and Cretaceous carbonates (Mattavelli and Margarucci, 1992). Lateral and top seals are provided by Cretaceous marls and argillaceous limestones and thick Oligo-Miocene flysch. In areas of more intense faulting, substantial amounts of gas escaped into Pliocene reservoirs and mixed with indigenous biogenic gas (e.g. Caviaga field; Mattavelli et al., 1983).

As the Rhaetian source-rocks are not present in the compressionally deformed Malossa palaeohorst, its charge was probably provided by a lateral graben-shaped basin. These source-rocks have a generation potential of 1-3 kg HC/t and are several hundreds of meters thick (SPI value between 1 and 2 t HC/m^2); as type III kerogen predominates, they have a limited oil potential and are gas prone. This accords with the low gravity of the Malossa condensate (53° API) and a GOR of 1000. Overpressures were responsible for the presence of a monophase hydrocarbon fluid in the reservoir with a dew point of 398 kg/cm^2 (39 MPa=5661 psi). The burial history of such a basin, derived from wells and seismic data, suggests that hydrocarbon generation and expulsion started already during the Early Jurassic (Mattavelli and Margarucci, 1992), possibly charging extensional traps. This is supported by the presence of pyrobitumens with different maturity levels. Much of these earlier entrapped hydrocarbons were probably lost to surface during the Middle-Late Miocene deformation of the Lombardy thrustbelt. The Malossa gas-condensate was probably charged during the Plio-Pleistocene subsidence of the Po Basin.

We conclude that the Riva di Solto petroleum system is probably undercharged, depends on lateral and vertical migration and is characterized by a poor seal integrity.

Mesozoic Emma System of Central Adriatic

In the Pescara Trough of the central Adriatic, Late Pliocene frontal elements of the Apennines involve foreland inversion structures. In these, the Late Cretaceous-Late Eocene Scaglia Formation, which consists mainly of pelagic marly carbonate, contains in turbiditic calcarenite intercalations. These form the reservoir of several accumulations of sulphur-rich (4-10%) heavy oils (7-20° API) (e.g. Gianna field). Geochemical data show that these oils are early expulsion products of the Late Triassic Emma Limestone, encountered in boreholes. The high sulphur content of these oils suggests a low activation energy for the kerogens (Mattavelli and Novelli, 1990; Mattavelli et al., 1991, 1992a).

The Pescara Trough is characterized by a low geothermal gradient (av. 22°C/km) and rapid Plio-Pleistocene subsidence/sedimentation rates (up to 1000 m/Ma). Subsidence analyses show that the Emma Limestone entered the oil window only during the Late Neogene at a depth of more than 5000 m. At the same time, Cretaceous and Paleogene carbonates were compressionally deformed. Expelled oils migrated vertically into the growing structures; their accumulation in calcarenitic layers presumably impeded diagenetic processes and preserved their original porosity. As the fractured marly limestones of the Scaglia Formation have a limited seal potential, some oil escaped and accumulated in Miocene carbonates (Alanno and other minor onshore fields).

The Emma petroleum system is probably undercharged, depends on vertical migration and has a poor seal integrity.

Mesozoic Burano System of Southern Adriatic

The Rospo oil field was discovered in 1975 (André and Doulcet, 1991; Héritier et al., 1991). Its heavy (11° API) and sulphurous (6%), immature oil was generated by anoxic Late Triassic Burano carbonates, which underwent a similar thermal history as the Emma Limestone (Mattavelli et al., 1991). The reservoir is formed by karstified

Albian-Cenomanian limestones, sealed by Messinian anhydrites and marly limestones. The trap is of a paleotopographic-diagenetic type and is mainly hydrodynamically controlled.

The southern parts of the Adriatic Sea are separated from the Apennines by the Puglia Platform and as such are closer associated with the Dinarides-Hellenic foreland basin. The Rovesti and Aquila oil accumulations are located to the East of the Puglia Platform in small Miocene horst blocks, down-faulted with respect to the Puglia Platform (Encl. 3, sect 6). Of the two accumulations, the Aquila field is scheduled for development by means of horizontal wells (Oil and Gas Journal, 1993). Its reservoir is formed by high-porosity (15%) turbiditic calcarenites of the Scaglia Formation which is unconformably overlain and sealed by Oligocene marls. The turbidites were derived from the Puglia Platform.

According to biomarkers, the oils of both accumulations belong to the same family (Paulucci et al., 1988) and show similarities with oil-extracts from the Late Triassic Burano Formation. The Aquila oil is under-saturated and vertically density stratified (36-22°API; Schlumberger, 1987). Numerical simulations indicate that the source-rock entered the oil window oil during the Late Cretaceous (±70 Ma) and that gas-condensate generation commenced during the Late Oligocene (±25 Ma). The main oil expulsion phase occurred during the Late Eocene (45-40 Ma; Mattavelli et al., 1991).

Despite an analogue source-rock and reservoir model, the evolution of the Aquila area differs considerably from the Emma area. Low maturity heavy oils may not have been expelled from the source-rock due to lack of fracturing and may later have been cracked to lighter oils (Palacas, 1983).

Available data do not allow to assess the charge factor of the Burano Petroleum System; migration is probably vertical and seal integrity is good.

Mesozoic Noto-Streppenosa System of Southeast Sicily

The on- and off-shore fields of southeastern Sicily account for most of Italy's URR of oil. Oils are characterized by low gravity (5-20° API) and a high sulphur content (2.6-9.8%); well preserved n-alkanes indicate that they are not biodegraded but are early expulsion products of the Noto and Streppenosa source-rocks (Fig. 6; Pieri and Mattavelli, 1986; Mattavelli and Novelli, 1990). The genetic potential of these source-rocks is rather low, with SPI value estimated at about 3 t HC/m^2. Expelled oils migrated into Late Triassic platform dolomites, sealed by the Noto-Streppenosa series (e.g. Gela and Ragusa fields), and into Early Jurassic limestones deposited on a platform, prograding over the source-rocks, which is sealed by Early Jurassic argillaceous limestones and marls (e.g. Vega and Perla fields). The integrity of these seals was reduced by Tertiary tectonics, as evident by asphalt seeps and frequent shows in post-Jurassic series. Traps are provided by faulted anticlines (e.g. Ragusa and Gela fields) which developed in response to Late Neogene compressional reactivation of Jurassic extensional structures. In contrast, the off-shore Vega field is contained in a Late Cretaceous combination trap.

Numerical modelling indicates that in the area northwest of Gela, the main phase of oil generation occurred during the last 5 Ma when the Sicily Apennine foredeep basin developed (Novelli et al., 1988). Strong subsidence of the foredeep initiated the onset of oil generation and expulsion at low maturity levels, particularly from the Noto Formation. High heat-flow, related to rifting activity on the Pelagian Shelf and Tyrrhenian Sea, may have contributed to maturation. Conversely, the burial history of the Noto Formation in the drainage area of the Vega field indicates that oil generation commenced during the Paleocene and peaked during the Late Miocene-Pliocene and, as such, clearly post-dates trap formations (Schlumberger, 1987).

In conclusion, the petroleum system of southeastern Sicily is undercharged, depends on lateral migration and is characterized by a relatively poor seal integrity.

Miocene Flysch System of Po Plain and Emila Folds

The Cortemaggiore gas-oil field and additional minor oil accumulations are located in the Emilia Arc, a major subsurface unit of the external Northern Apennine (Pieri and Groppi, 1981; Pieri, 1992). The Cortemaggiore accumulation is contained in a thrust-anticline; clean, well sorted Messinian sands contain wet gas and Tortonian sands light oil (35-40° API). Minor amounts of thermal gas leaked into Pliocene reservoirs where they mixed with biogenic gas (e.g. Spilamberto field; Mattavelli et al., 1983). Trap formation commenced during the Late Miocene and persisted into Plio-Pleistocene times (Pieri, 1992). Thrust structures, detached from Mesozoic carbonates, are cored by Miocene flysch and are unconformably overlain by Messinian marls and sands, Pliocene shales and Pleistocene sands.

Bio-markers, carbon isotope values and pristane/phytane ratios permit to differentiate between the Cortemaggiore oil group from Mesozoic oils (Riva et al., 1986). The presence of oleanane, an Angiosperm-derived bio-marker (Moldowan et al., 1993), is indicative of land-plant derived kerogen, and suggests that hydrocarbons were sourced by the 800-1000 m thick Langhian-Tortonian Marnoso-arenacea flysch succession which has a SPI of 1.6-2.0 t HC/m^2 (Mosca and Dalla, 1993). Mathematical modelling shows that oil generation occurred during the last 3 Ma at depths of 5500 to 7000 m (Chiaramonte and Novelli, 1986). Rapid Neogene thrust-loaded subsidence and deep burial favoured the generation of thermal gas, amounting in energy equivalents to 12 times the oil reserves of this province (Mattavelli and Novelli, 1990).

The Cortemaggiore petroleum system must be regarded as undercharged, depends on vertical migration and is characterized by a poor to adequate seal integrity.

Tortonian Biogenic Gas Systems

Tortonian biogenic gas plays a subordinate role in the hydrocarbon habitat of Italy. In the Veneto, the small Conegliano biogenic gas field is reservoired in Tortonian carbonate sands involved in a Pliocene anticlinal structure. In Western Sicily turbiditic sands of the Terravecchia Formation, involved in a Pliocene fold, host the small Lippone-Mazara biogenic gas accumulation. In the southern Adriatic, the Falco-1 well, drilled in the vicinity of the Aquila oil field, established a biogenic gas accumulation in Pliocene and Messinian sands and Tortonian limestones (Paulucci et al., 1988).

Plio-Pleistocene Biogenic Gas Systems

Bacterial gas, associated with the immature Plio-Pleistocene turbiditic series of the Apennine foredeep, is by far the most important hydrocarbon resource of Italy (Mattavelli et al., 1983; Mattavelli and Novelli, 1988). 70% of the biogenic gas reserves are located in the Northern Apennine foredeep and in the Northern Adriatic Sea where high subsidence rates and a low geothermal gradient were conducive to the generation and preservation of large volumes of bacterial gas; moreover, basin-plain highly efficient turbidites (Mutti, 1985) provide for an excellent sand-shale ratios and laterally continuous sand sheets. In contrast, the Southern Apennine foredeep is characterized by laterally discontinuous, channelized turbidite sands. Generation of biogenic gas was syn-sedimentary and is probably still going on.

Main traps are provided by synsedimentary thrust-anticlines (e.g. Ravenna field) and by gentle anticlines adjacent to the thrustfront (e.g. Porto Garibaldi-Agostino field). In the northwestern Po Plain, structural, stratigraphic and combination traps are associated with the Messinian unconformity (e.g. Sergnano and Caviaga fields). In the same area, up-dip shale-outs of sands provides for stratigraphic traps (e.g. Settala field). The large Barbara field in the Northern Adriatic Sea is contained in a gentle drape fold. Gas often occurs in stacked accumulations, separated by less than 1 m thick clays. Gas saturations give rise to reflection-seismically detectable direct hydrocarbon indicators (amplitude/frequency anomalies) (Pieri and Mattavelli, 1986; Schlumberger, 1987; Mattavelli et al., 1988; Mattavelli and Novelli, 1988). In the Southern Apennine foredeep, gas can be trapped in palaeotopographic and /or structural highs upheld by Mesozoic carbonates, unconformably sealed by Pliocene shales (e.g. Grottole field), and in stratigraphic and combination traps involving Plio-Pleistocene sands (Sella et al., 1990, 1992).

Small extensional basins associated with the opening of the Tyrrhenian Sea contain minor biogenic gas accumulations in Plio-Pleistocene shallow marine sands (e.g. Tombolo field).

Petroleum Systems Related to Uncertain Source-Rocks

Quite a number Italian oil and gas accumulations were charged from source-rocks which, so far, have not yet been identified. However, in some cases, their stratigraphic position can be inferred from geochemical data.

The **Cavone and Bagnolo oil fields**, located in the external part of the Ferrara foldbelt of the Northern Apennine, are probably related to Triassic source-rocks. Both oils are heavy (20-23° and 16° API, resp.) and sulphur rich (3-4 and 5%, resp.) but differ in their carbon isotope compositions ($d^{13}C$: Cavone -28.9 to -30.8%°, Bagnolo -22.5%°). Molecular parameters are similar to the Besano-Meride system. In the area of these fields, inferred Triassic source-rocks are located at depths of 5000 to 7000 m and attained maturity during the last 6.5 Ma (Wygrala, 1988).

The Cavone field is contained in a dissected, thrust anticlinal structure, involving Early Jurassic and Cretaceous carbonate reservoirs, sealed by Middle Jurassic marly limestones and Early Cretaceous marls (Nardon et al., 1991); Neogene compressional deformation of a pre-existing Jurassic extensional fault block reduced the seal capacity and allowed gas to escape to the surface. The reservoirs of the Bagnolo field are formed by Cretaceous platform carbonates, sealed by Late Miocene shales.

The marginal **Ripi field**, located to the Southeast of Rome, was probably also charged by Triassic source-rocks. The area is heavily tectonized, permitting hydrocarbons to migrate vertically through fractured Mesozoic and Miocene carbonates into an irregularly structured Tortonian sand-shale sequence. Discovered during the past century on the basis of oil seeps, this field produced during the past years on average 1000 t/y (7300 bbl/y) of 21° API oil with a sulphur content of 3.7%.

The **Castelpagano group of small oil accumulations**, located in the Southern Apennine northeast of Naples, produce 30-43° API, low sulphur oil from Early Miocene and Cretaceous limestones, involved in parautochthonous thrust structures covered by the Lagonegro nappe (Encl. 4, sect. 5). The presence of oleanane in the Castelpagano oil suggests a Tertiary origin. Possible source-rocks are Messinian shales which have a TOC content of 0.95-1.25 and a generation potential of 3-5.2 kg HC/t. These oils are similar to those associated with biogenic gas, reservoired in Pliocene sands, in the eastwards adjacent Candela and Torrente Tona fields (Mattavelli and Novelli, 1990; Casero et al., 1991).

The Costa Molina group of oil fields of the Southern Apennine are also trapped in parautochthonous compressional structure beneath the Lagonegro nappe (Encl. 3, sect. 6 Mostardini and Merlini, 1988). Production comes from low porosity Cretaceous and Miocene carbonates, sealed by tight Miocene limestones and/or marls of the Lagonegro nappe. The limited capacity of these seals is indicated by oil seeps. Oil gravities range between 12.6 and 20.6° API and sulphur content is around 3%. Molecular parameters seem to suggest a Late Triassic-Early Jurassic source for these oils (Mattavelli and Novelli, 1990). However, recently an organic-rich Cretaceous facies has been prposed as a potential source candidate for similar oil in the Tempa Rossa field (Roure and Sassi, 1995). Numerical modelling indicates that oil generation and expulsion set in during the Late Neogene (Casero et al., 1991).

In the Ionian Sea, off-shore Calabria, the **Luna gas field** produces from Serravallian-Tortonian conglomerates and sands (porosity 9-22%), sealed by Tortonian and Pliocene clays and marls; these are involved in the external parts of the upper allochthonous units (Schlumberger, 1987; Roveri et al., 1992). This clearly thermal gas contains minor amounts of ethane and propane and is devoid of non-hydrocarbon gases. Heavy isotope values of methane suggest that it was generated at depths >6000 m from an unknown source rock, presumably during the Late Neogene.

In northeastern Sicily, the **Gagliano group of gas-condensate fields** produce from low porosity quartzose Oligo-Miocene turbiditic sands of the allochthonous Numidian Flysch. The gas has clearly a thermal origin; associated condensate (55° API) contains small amounts of oleanane, indicating at least a contribution from Tertiary sources. The trap-providing imbricated thrust-anticlines developed only in Early Pliocene times and have a limited retention potential, as indicated by frequent seeps (Schlumberger, 1987; Mattavelli and Novelli, 1990).

In the Sicily Channel, the **Narciso group of small oil fields** are reservoired in low-porosity (5%) Oligocene fossiliferous limestones involved in thrust structures which are partly overridden by the Flysch nappes. The 21-39° API oil, containing 1-2% of sulphur, was probably generated by Mesozoic source-rocks of unknown age. The presence of a CO_2 gas cap in the Nilde field must be related to volcanic activity associated with the development of the Pantelleria rift system (Schlumberger, 1987).

CONCLUSIONS

The hydrocarbon accumulations of Italy are concentrated in the external parts of the Alpine and Appennine fold- and thrustbelts and their forelands. A schematic sketch of the main petroleum plays of Italy is shown in Fig. 12. Minor accumulations occur, however in the more internal parts of the Apennines. The bulk of Italy's ultimate recoverable hydrocarbon reserves consists of biogenic gas contained in Plio-Pleistocene turbiditic sands of the Northern Apennine foredeep basin. Italy's oil and gas accumulations can be attributed to a number of more or less well defined petroleum systems.

The Middle Triassic-Early Jurassic petroleum systems are related to the development of isolated larger and smaller anoxic depressions within expansive carbonate platforms, resulting from early rifting phases, preceding the opening of the Alboran-Liguria-Piedmont ocean and the isolation of the Adria plate during the separation of Africa from Europe. Shaly and carbonate dominated source-rocks, partly associated with evaporites, which were deposited in these depressions, can attain thicknesses of 2 km and more. Their TOC content varies vertically and laterally and reaches maxima during transgressive periods, giving rise to a reduction of carbonate influx from flanking platforms.

Compared with world-wide examples of source-rocks, the SPI of Italian Middle Triassic to Early Jurassic source-rocks is low (Fig. 13). Correspondingly, its Triassic-Early Jurassic petroleum systems are generally undercharged. Moreover, it must be realized that the distribution of potential source-basins beneath the thick sedimentary fill of the foreland basins and particularly under the Apennine nappes is largely unknown. It is interesting to note, that on a global scale, Triassic source-rocks represent only 1.2% of all known source-rocks (Klemme and Ulmishek, 1991) whereas the bulk of Italian oils were generated by Triassic source-rocks. In many parts of Italy these reached maturity only during the Neogene empacement of the Alpine and Apennine nappes and the associated rapid flexural subsidence of the respective foreland basins; the Mesozoic Aquila and Vega kitchens are exceptions.

Unlike in other Tethys realm basins, Middle Jurassic to Cretaceous source-rocks play a very subordinate role in the hydrocarbon habitat of Italy. A probable exception is the Costa Molina petroleum system.

During the Alpine orogenic cycle, the rather lean Miocene flysch petroleum system developed, which plays a role in the Po Plain, the Emila foldbelt and in the Castelpagano area of the Southern Apennine. Bacterial gas was also generated in the shaly Miocene series of the eastern Southern Alps, the Southern Adriatic and in Western Sicily.

During the Neogene emplacement of the Apennine nappes, huge thicknesses of Plio-Pleistocene flysch series accumulated in the Po Plain and the Northern Adriatic foreland basin. High sedimentation rates, low temperature gradients, the availability of multiple reservoir seal pairs involving laterally continuous turbiditic sands and hemipelagic shales, and syndepositional compressional deformations provided ideal conditions for

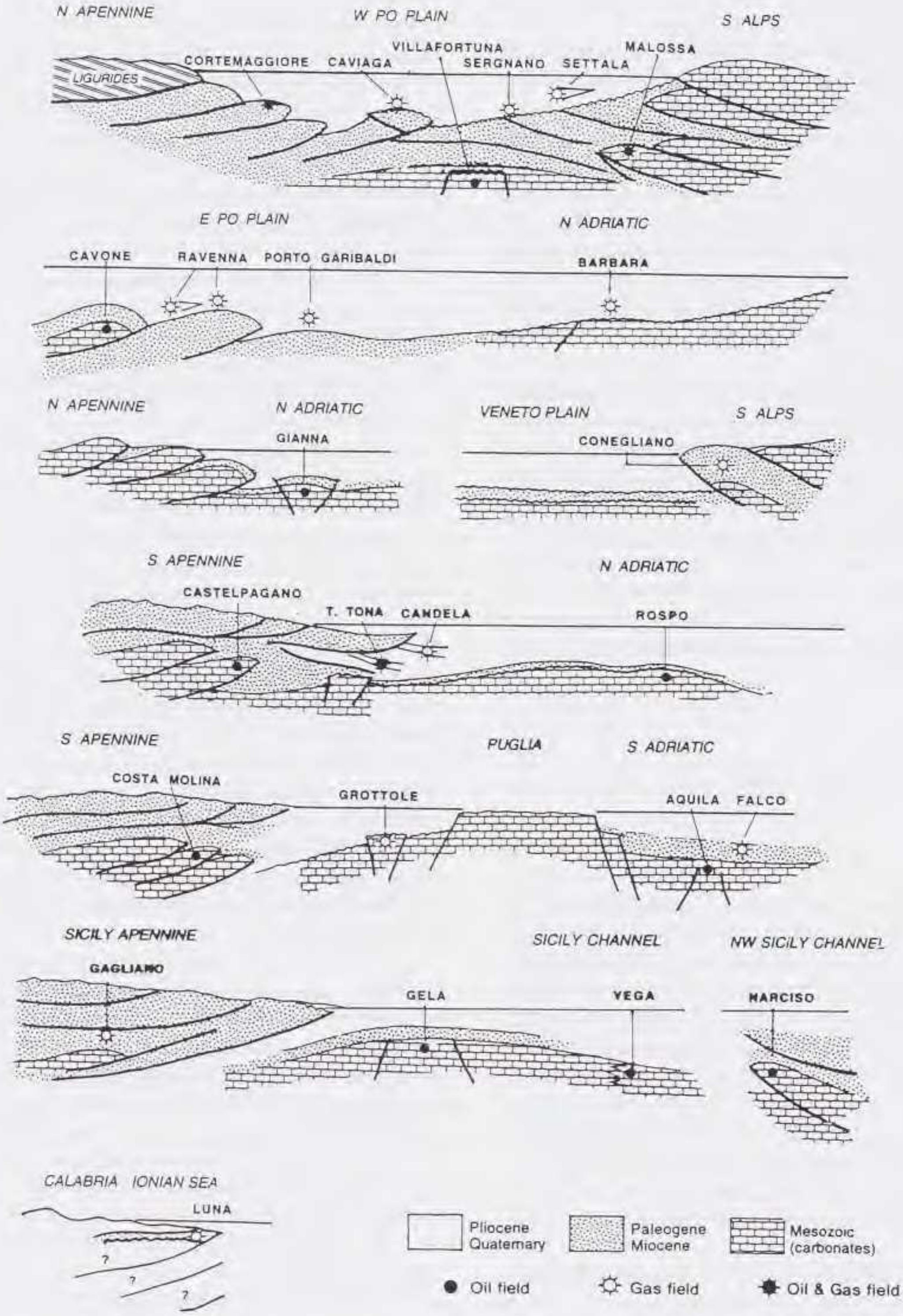


FIG. 12. Schematic sketches of the main Petroleum Plays in Italy.

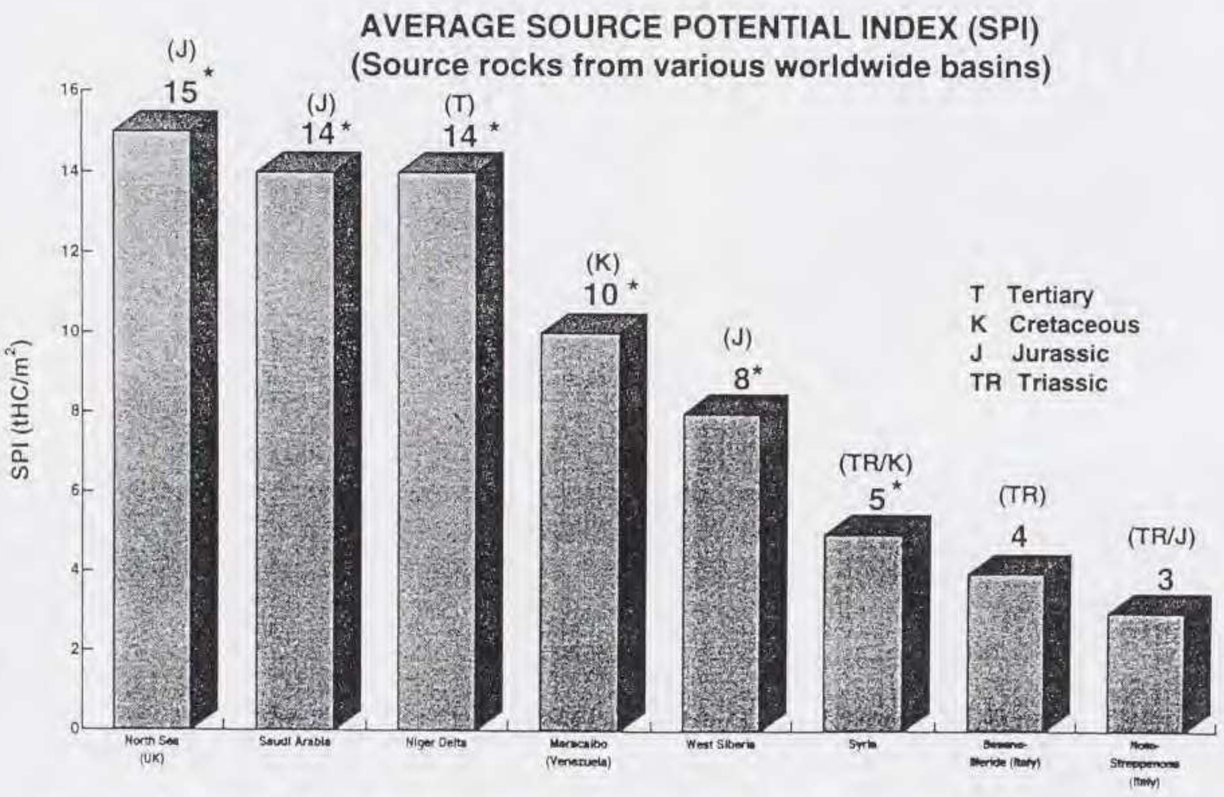


FIG. 13. Average Source Potential Index (SPI) of some petroleum systems (data after Demaison and Huizinga, 1991).

the generation and entrapment and retention of bacterial gas, accounting for 70% of Italy's hydrocarbon resources. In the Southern Apennine foredeep and in the Peri-Tyrrhenian Neogene basins such ideal conditions were not realized.

Sub-thrust plays, aiming at Mesozoic and Cenozoic objectives in compressional foreland and parautochthonous structures, covered by the Apennine nappes, have met with success in the Castelpagano and Costa Molina areas of the Southern Apennine. Such plays have to contend with difficulties in reflection-seismic prospect definition, and above all, with hydrocarbon charge uncertainties.

At present, Italy's recoverable hydrocarbon reserves consist to 87% of biogenic gas and to 13% of Triassic oil. Future discoveries in frontier areas, such as the external thrustbelts and the deep Mesozoic objectives of the foreland basins could change this situation.

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REFERENCES

Adamoli, L., A. Bigozzi, G. Ciarapica, S. Cirilli, L. Passeri, A. Romano, F. Duranti and F. Venturi (1990), "Upper Triassic bituminous facies and Hettangian pelagic facies in the Gran Sasso range". *Boll. Soc. Geol. It.*, **109**, pp. 219-230.

André, P. and A. Doulcet (1991), Rospo Mare Field - Italy, Apulian Platform, Adriatic Sea. In *Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Stratigraphic Traps II*, pp. 29-54.

Bernasconi, S. and A. Riva (1993), Organic geochemistry and depositional environments of a hydrocarbon source rock: the Middle Triassic Grenzbitumenzone Formation, Southern Alps, Italy-Switzerland. In *Generation accumulation and production of Europe's hydrocarbons* (Edited by Spencer, A.M.), *Europ. Assoc. Petrol. Geosci., Spec. Publ.*, **3**, pp. 179-190.

Bernoulli, D., C. Caron, P. Homewood, O. Kälin and J. van Stijvenberg (1979a), "Evolution of continental margins in the Alps". *Schweiz. Mineral. Petrogr. Mitt.*, **59**, pp. 165-170.

Bernoulli, D., O. Kälin and E. Patacca (1979b), "A sunken continental margin of the Mesozoic Tethys: the Northern and Central Apennines". *Assoc. Sédim. Franç., Symposium "Sedimentation jurassique W européen", Spec. Publ.*, **1**, pp. 197-210.

Bertotti, G., V. Picotti, D. Bernoulli and A. Castellarin (1993), "From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous". *Sed. Geol.*, **86**, pp. 53-76.

Biju-Duval, B., J. Dercourt and X. Le Pichon (1976), From the Tethys ocean to the Mediterranean seas: a plate tectonic model of the evolution of the western Alpine system. In *Structural history of the Mediterranean basins*. Ed. Technip, Paris, pp. 143-164.

Boccaletti, M., N. Ciaranfi, D. Cosentino, G. Deiana, R. Gelati, F. Lentini, F. Massari, G. Moratti, T. Pescatore, F. Ricci Lucchi and L. Tortorici (1990), "Palinspastic restoration and paleogeographic recontruction of the peri-Thyrrenian area during the Neogene". *Palaeogeogr., Palaeoclim., Palaeoecol.*, **77**, pp. 41-50.

Bongiorni, D. (1987), "La ricerca di idrocarburi negli alti strutturali mesozoici della Pianura Padana: l'esempio di Gaggiano". *Atti Ticinesi Scienze della Terra*, **31**, pp. 125-141.

Boni, M., A. Iannace, J. Koster and M. Parente (1990), "Anoxic facies in the Upper Triassic of Picentini Mountains (southern Apennines, Italy)". *Boll. Soc. Geol. It.*, **109**, pp. 171-185.

Brosse, E., J.P. Loreau, A.Y. Huc, A. Frixa, L. Martellini and A. Riva (1988), "The organic matter of interlayered carbonates and clays sediments, Trias/Lias, Sicily". *Organ. Geochem.*, **13**, pp. 433-443.

Casero, P., F. Roure and R. Vially (1991), Tectonic framework and petroleum potential of the southern Apennines. In *Generation, accumulation and production of Europe's hydrocarbons* (Edited by Spencer, A.M.), *Europ. Assoc. Petrol. Geosci., Spec. Publ.*, **1**, pp. 381-387.

Cassano, E., L. Anelli, R. Fichera and V. Cappelli (1986), *Pianura Padana: interpretazione integrata dei dati geofisici e geologici. Soc. Geol. It., 73th Congresso, 29 sett.-4 ott., Roma, annex to Boll. Soc. Geol. It.*, **106**, 4, 127 p.

Catalano, R. and B. D'Argenio (1983), "Infraliassic strike-slip tectonics in Sicily and southern Apennines". *Rend. Soc. Geol. It.*, **5**, pp. 5-10.

Chiaramonte, M.A. and L. Novelli (1986), "Organic matter maturity in northern Italy: some determining agents". *Organ. Geochem.*, **10**, pp. 281-290.

Ciarapica, G., S. Cirilli, B. D'Argenio, E. Marsella, L. Passeri and L. Zaninetti (1987), "Late Triassic open and euxinic basins in Italy". *Rend. Soc. Geol. It.*, **9**, pp. 157-166.

Consiglio Nazionale delle Ricerche (1989), *P. F. Geodinamica, Sottoprogetto Modello Strutturale, Synthetic structural-kinematic map of Italy. Scale 1:2,000,000.*

Creaney, S. and Q.R. Passey (1993), "Recurring patterns of total organic carbon and source rock quality within a sequence stratigraphic framework". *Am. Assoc. Petrol Geol. Bull.*, **73**, 3, pp. 386-401.

D'Argenio, B., T. Pescatore and P. Scandone (1973), "Schema geologico dell'Appennino meridionale (Campania ed Lucania). Atti del Convegno: Moderne vedute sulla geologia dell'Appennino". *Acc. Naz. Lincei*, **183**, pp. 49-72.

Demaison, E. and B.J. Huizinga (1991), "Genetic classification of Petroleum Systems". *Am. Assoc. Petrol Geol. Bull.*, **75**, 10, pp. 1626-1643.

Dercourt, J., L.P. Zonenshain, L.E. Ricou, V.G. Kazmin, X. Le Pichon, A.L. Knipper, C. Grandjacquet, I.M. Sborshikov, O. Boulin, J. Sorokhtin, J. Geyssant, C. Lepvrier, B. Biju-Duval, J.C. Sibuet, L.A. Savotsin, M. Westphal and J.P. Lauer (1985), "Présentation de 9 cartes paléogéographiques au 1/20,000.000 s'étendant de l'Atlantique au Pamir pour la période du Lias à l'actuel". *Bull. Soc. géol. France*, **8**, I(5), pp. 637-652.

Dercourt, J., L.P. Zonenshain, L.E. Ricou, V.G. Kazmin, X. Le Pichon, A.L. Knipper, C. Grandjacquet, I.M. Sbortshikov, J. Geyssant, C. Lepvrier, D.H. Pechersky, J. Boulin, J.C. Sibuet, L.A. Savostin, O. Sorokhtin, M. Westphal, M.L. Bazhenov and J.P. Lauer (1986), "Geological evolution of the Tethys belt from Atlantic to Pamir since Liassic". *Tectonophysics*, **123**, 1-4, pp. 241-315.

Dewey, J.F., M.L. Helman, E. Turco, D.H.W. Hutton and S.D. Knott, (1989), Kinematics of the western Mediterranean. In *Alpine Tectonics* (Edited by Coward,M.P., D. Dietrich and R.G. Park), *Geol. Soc., London, Spec. Publ.*, **45**, pp. 265-283.

Doglioni, C. and A. Bosellini (1987), "Eoalpine and mesoalpine tectonics in the Southern Alps". *Geol. Rundsch.*, **76**, 3, pp. 735-754.

Errico, G., G. Groppi, S. Savelli and G.C. Vaghi (1980), "Malossa field: a deep discovery in the Po Valley, Italy". In *Giant fields of the decade 1968-1978, Am. Assoc. Petrol Geol., Mem.*, **30**, pp. 525-538.

Farrimond, P., G. Eglington, S.C. Brassell and H.C. Jenkins (1990), "The Cenomanian/Turonian anoxic event in Europe: an organic geochemical study". *Mar. Petrol. Geol.*, **7**, pp. 75-89.

Gaetani, M., M. Gnaccolini, G. Poliani, D. Grignani, M. Gorza and L. Martellini (1991), "An anoxic intraplatform basin in the Middle Triassic of Lombardy (Southern Alps, Italy): anatomy of a hydrocarbon source". *Riv. It. Paleont. Strat.*, **97**, 3-4, pp. 329-354.

Hao Fang, Sun Yongchuan, Li Sitian and Zhang Qiming (1995), "Overpressure Retardation of Organic-Matter Maturation and Petroleum Generation: A Case History from the Yinggehai and Qiongdongnan Basins, South China Sea". *Am. Assoc. Petrol. Geol. Bull.*, **79**, 4, pp. 551-562.

Héritier, F., P. André and A. Doulcet (1991), Rospo Mare oil field (Italy). An example of multitechnical appraisal and development. In *Petroleum basins of Europe* (Edited by Spencer, A.M.), *Europ. Assoc. Petrol. Geosci., Spec. Publ.*, **1**, pp. 399-414.

Hsü, K.J., L. Montadert, D. Bernoulli, M.B. Cita, A. Erikson, R.B. Garrison, R.B. Kidd, F. Mèlierés, C. Müller and R. Wright (1977), "History of the Mediterranean salinity crisis". *Nature*, **267**, pp. 399-403.

Hunt, J.M. (1990), "Generation and migration of petroleum from abnormally pressure fluid". *Am. Assoc. Petrol. Geol. Bull.*, **74**, 1, pp. 1-12.

Jadoul, F. (1985), "Stratigrafia e paleogeografia del Norico nelle Prealpi Bergamasche occidentali". *Riv. It. Paleont. Strat.*, **91**, 4, pp. 479-512.

Katz, B.J. and L.M. Pratt (Eds) (1993), Source rocks in a sequence stratigraphic framework. *Am. Assoc. Petrol. Geol., Studies in Geology*, **37**, pp. 1-247.

Klemme, H.D. and G.H. Ulmishek (1991), "Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors". *Am. Assoc. Petrol. Geol. Bull.*, **75**, 12, pp. 1809-1851.

Koster, J., H. Wenher and H. Hufnagel (1988), Organic geochemistry and organic petrology of organic rich sediments within the Hauptdolomit formation (Triassic, Norian) of the Northern Calcareous Alps. In *Advances in Geochemistry 1987, Organ. Geochem.*, **13**, 1-3, pp. 377-386.

Laubscher, H. and D. Bernoulli (1977), Mediterranean and Tethys. In *The Ocean Basins and Margins, The Eastern Mediterranean* (Edited by Nairn A.E.M., F.G. Stehli and W. Kanes), Plenum Publ. Corp., New York,4A, pp. 1-28.

Marsella, E., G. Pappone, B. D'Argenio, G. Cippitelli and A.W. Bally (1992), "L'origine interna dei terreni lagonegresi e l'assetto tettonico dell'Appennino meridionale". *Rend. Acc. Sc. fis. e mat. della Soc. Naz. di SC. Lett. ed Arti in Napoli*, **59**, pp. 73-101.

Mattavelli, L. and V. Margarucci (1992), Malossa Field - Italy. *In Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Structural Traps VII*, pp.119-133.

Mattavelli, L. and L. Novelli (1987), "L'origine des hydrocarbures dans les basin du Po". *Mém. Soc. géol. France, 151*, pp. 97-106.

Mattavelli, L. and L. Novelli (1988), "Geochemistry and habitat of natural gases in Italy". *Organ. Geochem.*, **13**, 1-3, pp. 1-13.

Mattavelli, L. and L. Novelli (1990), "Geochemistry and habitat of the Oils in Italy". *Am. Assoc. Petrol. Geol. Bull.*, **74**, 10, pp. 1623-1639.

Mattavelli, L., T. Ricchiuto, D. Grignani and M. Schoell (1983), "Geochemistry and Habitat of Natural gases in the Po Basin - Northern Italy". *Am. Assoc. Petrol. Geol. Bull.*, **67**, 12, pp. 2239-2254.

Mattavelli, L., L. Novelli and L. Anelli (1991), Occurrence of Hydrocarbons in the Adriatic basin. In *Generation, accumulation and production of Europe's hydrocarbons* (Edited by Spencer, A.M.), E*urop. Assoc. Petrol. Geosci., Spec. Publ.*, **1**, pp. 369-380.

Mattavelli, L., D. Grigo, M. Orlando and M. Rossi (1992a), "Neogene tectono-sedimentary evolution and hydrocarbon occurrence in the Adriatic area". *Paleontologia i evolucio*, **24-25**, pp. 377-391.

Mattavelli, L., T. Ricchiuto and G. Martinenghi (1992b), Deep isotopic light methane in northern Italy. In *Bacterial Gas Conference, Sept. 25-26, 1989, Milan* (Edited by Vially, R.), Ed. Technip, Paris, pp. 121-132.

Mattavelli, L., M. Pieri and G. Groppi (1993), "Petroleum Exploration in Italy: a review". *Mar. Petrol. Geol.*, **10**, 5, pp. 410-425.

Moldowan, J.M., J.E. Dahl, B.J. Huizinga and S.R. Jacobson (1993), "The relationship of angiosperms and oleanane in petroleum through geological time". *Am. Assoc. Petrol. Geol. Bull.*, **77**, 9, pp. 334 (abstract).

Mosca, F. and S. Dalla (1993), "Organic matter distribution in the flysch deposits of the Marnoso Arenacea Formation, Miocene, northern Apennines, Italy". *Am. Assoc. Petrol. Geol. Bull.*, **77**, 9, pp.1648 (abstract).

Mostardini, F. and S. Merlini (1988), "Appennino centro meridionale, sezioni geologiche e proposta di modello strutturale". *Mem. Soc. Geol. It.*, **35**, pp. 177-202.

Müller-Jungbluth, W.U. (1968), Sedimentary petrology investigation in the Upper Triassic "Hauptdolomit" of the Lechtaler Alps, Tyrol, Austria. In *Recent developments in carbonate sedimentology in Central Europe* (Edited by Müller, G. and G.M. Friedman), Springer Verlag, Berlin, pp. 228-239.

Mutti, F. (1985), Turbiditic systems in their relation to depositional sequences. In *Provenance of arenites* (Edited by Zuffa, G.G.), D. Reidel Publ. Co., Dordrecht, pp. 65-93.

Nardon, S., D. Marzorati, A. Bernasconi, S. Cornini, M. Gonfalini, S. Mosconi, A. Romano and P. Terdich (1991), "Fractured carbonate reservoir characterization and modelling: a multidisciplinary case study from the Cavone oil field, Italy". *First Break*, **9**, 12, pp. 553-565.

Novelli, L., M.A. Chiaramonte, L. Mattavelli, G. Pizzi, L. Sartori and P. Scotti (1987), Oil Habitat in the North*western Po Basin. In Migration of Hydrocarbons in Sedimentary basins: 2nd IFP Exploration Research Conference* (Edited by Doligez, B.), Ed. Technip, Paris, pp. 27-57.

Novelli, L., D.H. Welte, L. Mattavelli, M.L. Yalcin, D. Cinelli and K. Schmidt (1988), Hydrocarbon generation in Southern Sicily. A three dimensional computer aided basin modeling study. In *Advances in Organic Geochemistry, 1987, Organ. Geochem.*, **13**, 1-3, pp. 153-164.

Oil and Gas Journal (1993), 9, Augustus, pp. 21-22.

Palacas, J.C. (1983), "Carbonate rocks as sources of petroleum: geological and geochemical characteristics and oil-source correlations". *11th World Petroleum Congress, Proceedeings*, **11**, pp. 31-70.

Patacca, E. and P. Scandone (1989), Post-Tortonian mountain building in the Apennines. The role of the passive sinking of a relic litospheric slab. In *The Lithosphere in Italy* (Edited by Boriani, A., M. Bonafede, G.B. Piccardi and G.B. Vai), Consiglio Nazionale delle Ricerche, Italian Committee for the International Litosphere Program, pp. 157-176.

Paulucci, G., L. Novelli, D. Bongiorni and R. Cesaroni (1988), "Deep Offshore Exploration in the Southern Adriatic Sea". *Offshore Technology Conference, OTC 5730*, pp.413-421.

Pieri, M. (1966), "Tentativo di ricostruzione paleogeografico-strutturale dell'Italia centro-meridionale". *Geol. Romana*, **5**, pp. 407-424.

Pieri, M. (1984), Storia delle ricerche nel sottosuolo padano fino alle ricostruzioni attuali. In *Cento anni di geologia italiana. Vol. giub. 1° Centenario*, Bologna, Soc.Geol.It., pp. 155-176.

Pieri, M. (1992), Cortemaggiore Field - Italy, Po Plain, Northern Apennines. In *Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Structural Traps VII*, pp. 99-118.

Pieri, M. and G. Groppi (1981), *Subsurface geological structure of the Po Plain, Italy*. Consiglio Nazionale delle Ricerche, Progetto finalizzato Geodinamica, Pubbl. 414, 13 p.

Pieri, M. and L. Mattavelli (1986), "Geologic Framework of Italian Petroleum Resources". *Am. Assoc. Petrol Geol. Bull.*, **70**, 2, pp. 103-130.

Riva, A., T. Salvatori, R. Cavaliere, T. Ricchiuto and L. Novelli (1986), "Origin of oils in Po Basin, Northern Italy". *Organ. Geochem.*, **10**, pp. 391-400.

Roure, F. and W. Sassi (1995), "Kinematics of deformation and petroleum system appraisal in Neogene foreland fold-and-thrust belts". *Petroleum Geoscience*, **1**, pp. 253-269.

Roveri, A., A. Bernasconi, M.E. Rossi and C. Visentin (1992), Sedimentary evolution of the Luna field area, Calabria, Southern Italy. In *Generation, Accumulation and Production of Europe's Hydrocarbons* (Edited by Spencer, A.M.), *Europ. Assoc. Petrol. Geosci., Spec. Publ.*, **2**, pp. 217-224.

Santantonio, M. (1994), "Pelagic Carbonate Platforms in the Geologic Record: Their Classification, and Sedimentary and Paleotectonic Evolution". *Am. Assoc. Petrol. Geol. Bull.*, **78**, 1, pp. 122-141.

Scandone, P., E. Patacca, C. Meletti, M. Bellatalia, N. Perilli and U. Santini (1992), "Struttura geologica, evoluzione cinematica e schema sismotettonico della penisola italiana". *Atti del Convegno GNDT 1990*, **1**, pp. 119-135.

Schlumberger Italiana (1987), *Well Evaluation Conference, Italia 1987*.

Sella, M., C. Turci and A. Riva (1990), Petroleum geology of the "Fossa Bradanica" (foredeep of the Southern Apennine thust belt). In *Classic Petroleum Provinces* (Edited by Brooks, J.), *Geol. Soc., London, Spec. Publ.*, **50**, pp. 369-378.

Sella, M., C. Turci, and A. Riva (1992), "Sintesi geopetrolifera della fossa bradanica (avanfossa della catena appeninicva meridionale)". *Mem. Soc. Geol. It.*, **41**, pp. 87-107.

Stefani, M. and M. Burchell (1990), Upper Triassic (Rhaetic) Argillaceous Sequences in Northern Italy: Depositional Dynamics and Source Potential. In *Deposition of Organic facies* (Edited by Huc, A.Y.), *Am. Assoc. Petrol Geol., Studies in Geology, 30*, pp. 93-106.

Stefani, M. and M. Burchell (1993), A review of the Upper Triassic source rocks of Italy. In *Generation accumulation and production of Europe's hydrocarbons* (Edited by Spencer, A.M.), *Europ. Assoc. Petrol. Geosci., Spec. Publ.*, **3**, pp. 169-178.

Tapponier, P (1977), "Evolution tectonique du système alpin en Mediterranée: poinçonnement et écrasement rigide-plastique". *Bull. Soc. géol. de France*, **19**, pp. 437-460.

Wygrala, B.P. (1988), "Integrated computer-aided basin modeling applied to analysis of hydrocarbon generation history in a Northern Italian oil field". *Organ. Geochem.*, **13**, 1-3, pp. 187-197.

Zappaterra, E. (1990), "Carbonate paleogeographic sequences of the Periadriatic Region". *Boll. Soc. Geol. It.*, **109**, 1, pp. 5-20.

Zappaterra, E. (1994), "Source-Rock Distribution Model of the Periadriatic Region". *Am. Assoc. Petrol. Geol. Bull.*, **78**, 3, pp. 333-354.

Ziegler, P. A. (1988), "Evolution of the Arctic-North Atlantic and the Western Tethys". *Am. Assoc. Petrol Geol. Mem.*, **43**, 198 p.

Ziegler, P.A. (1990), *Geological Atlas of Western and Central Europe, 2nd. Ed.* Shell Internationale Petroleum Mij. B.V., distrib. Geol. Soc., London, Publ. House, Bath, 239 p.

Enclosures

Enclosure 1 Geological cross-sections through the Northern and Central Italy.

Enclosure 2 Geological cross-sections through the Southern Italy.

Enclosure 3 Geological cross-sections through the Southern Italy and Sicily.